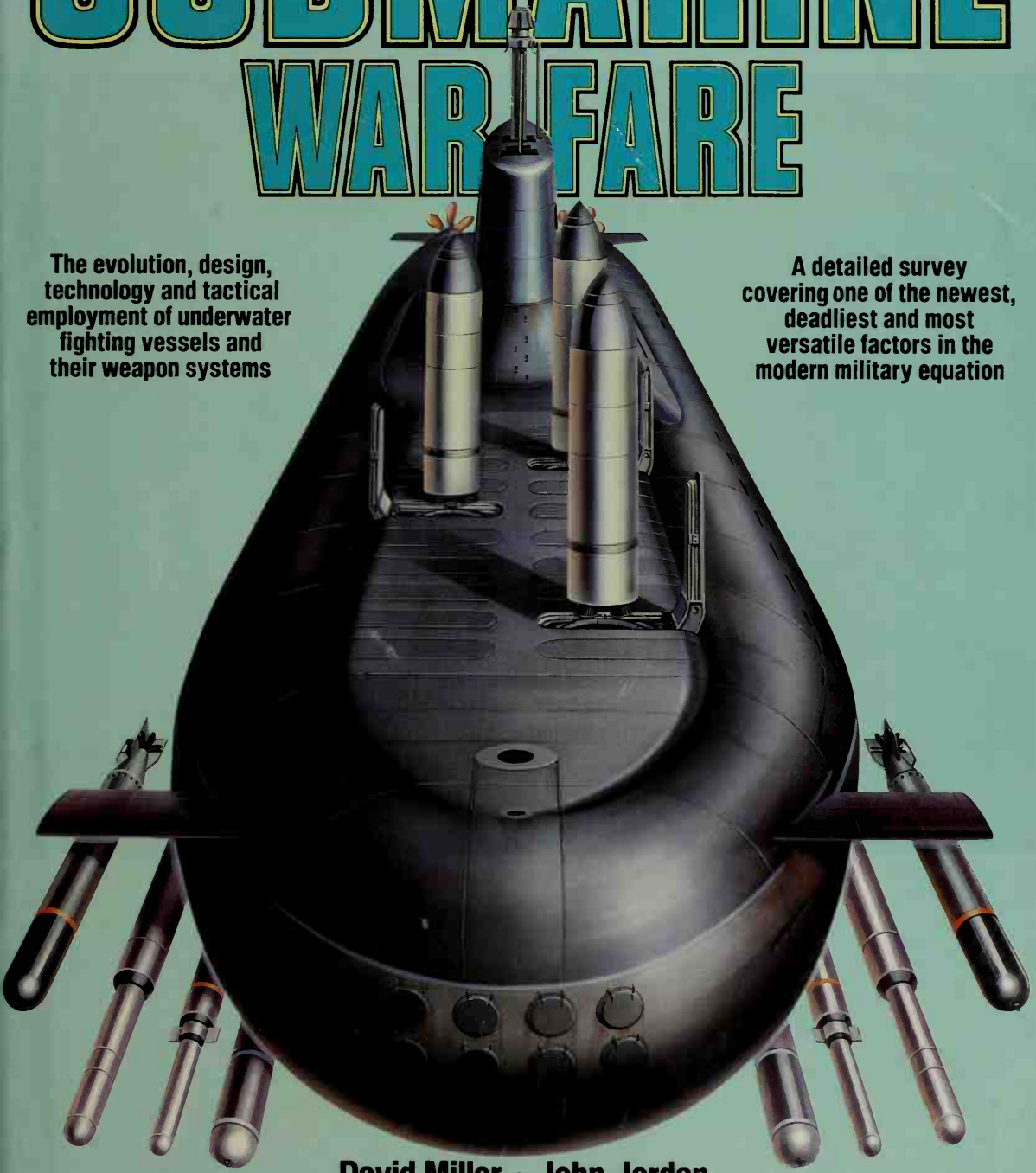
MODERN SUBMARINE WARFARE

The evolution, design, technology and tactical employment of underwater fighting vessels and their weapon systems

A detailed survey covering one of the newest, deadliest and most versatile factors in the modern military equation



David Miller • John Jordan

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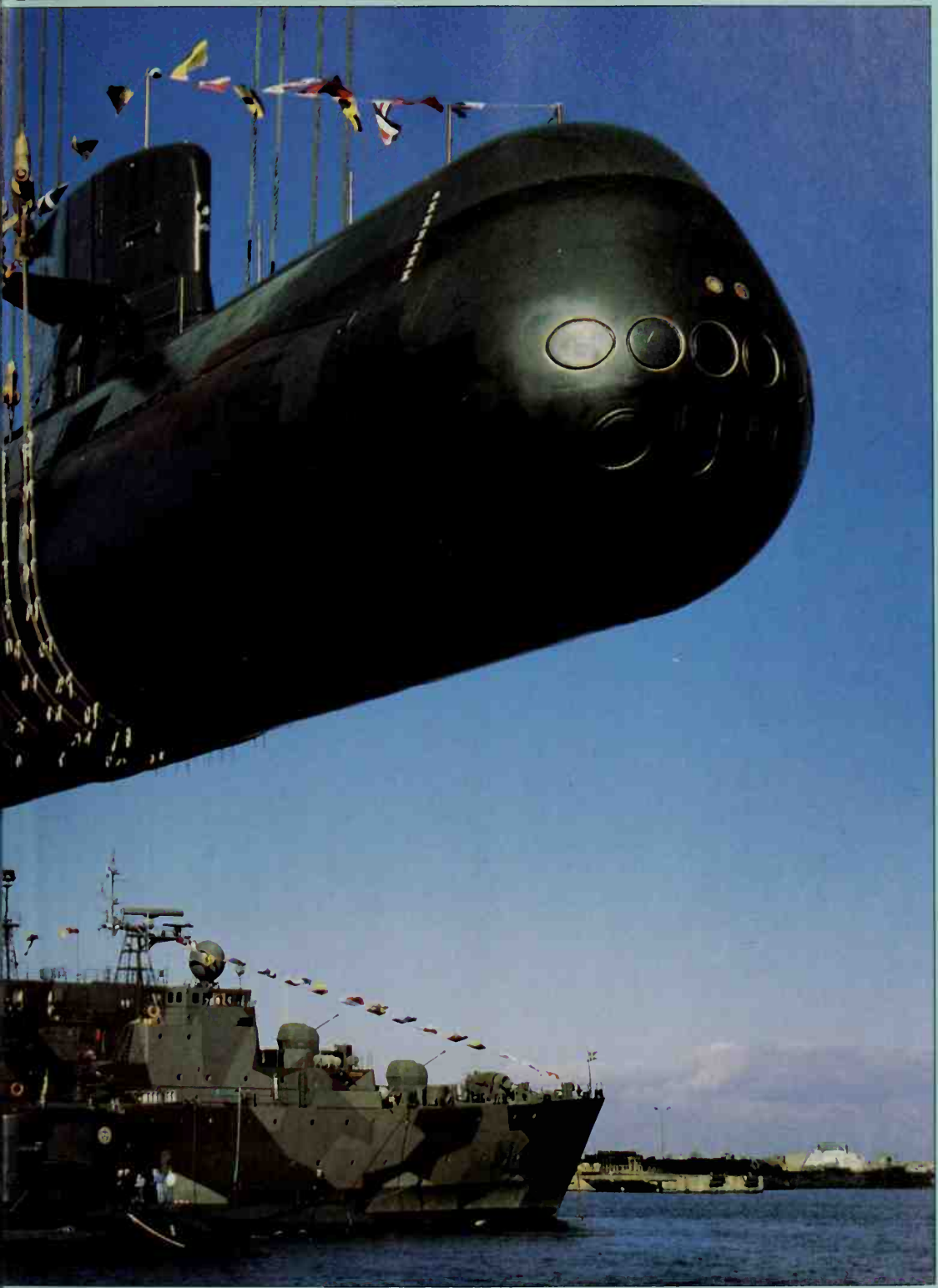
275 photographs
46 full-color perspectve drawings
More than 90 explanatory diagrams

Anyone who thinks a submarine is essentially just a metal tube with torpedoes in the front and a periscope on top will be astonished at the variety of shapes and sizes on display in the central section of this book. The range of sizes is explained by several factors, including the roles for which they were designed and the technological and economic resources available.

The number of variations on a fundamentally cylindrical shape is the result of other factors, which are examined in the first part of the book, where a brief historical introduction and a more detailed look at a handful of the most significant designs in the evolution of the submarine is followed by an examination of the underwater environment in which submarines must function and a survey of particular aspects of submarine technology. Construction, propulsion, weapons, sensors and communications are all discussed in general terms and illustrated by photographs and diagrams showing the function and operation of representative systems. Since all submarine design is dominated by considerations of the threats with which the resulting vessels will have to deal, surface antisubmarine warfare is also discussed in general terms and, again, a selection of representative systems is shown in photographic and diagrammatic form. Finally, since no navy which seeks to recruit personnel of suitable calibre and maintain a healthy level of morale can afford to overlook the possibility of accidents, the section concludes with a chapter on the modern escape and rescue systems that would help a crew survive in the aftermath of a disaster.

Having explored the technological aspects of submarine design and the specific forms which different builders have produced to meet the requirements and limitations under which they must work, the reader should be in a position to appreciate the tactical aspects of submarine and antisubmarine warfare which form the subject of the book's final section. Once again, photographs and diagrams combine to present a uniquely informative account of the methods employed by submarines and their hunters.

Above: Launch of the *Västergötland* by Kockums, Malmö, September 1986.



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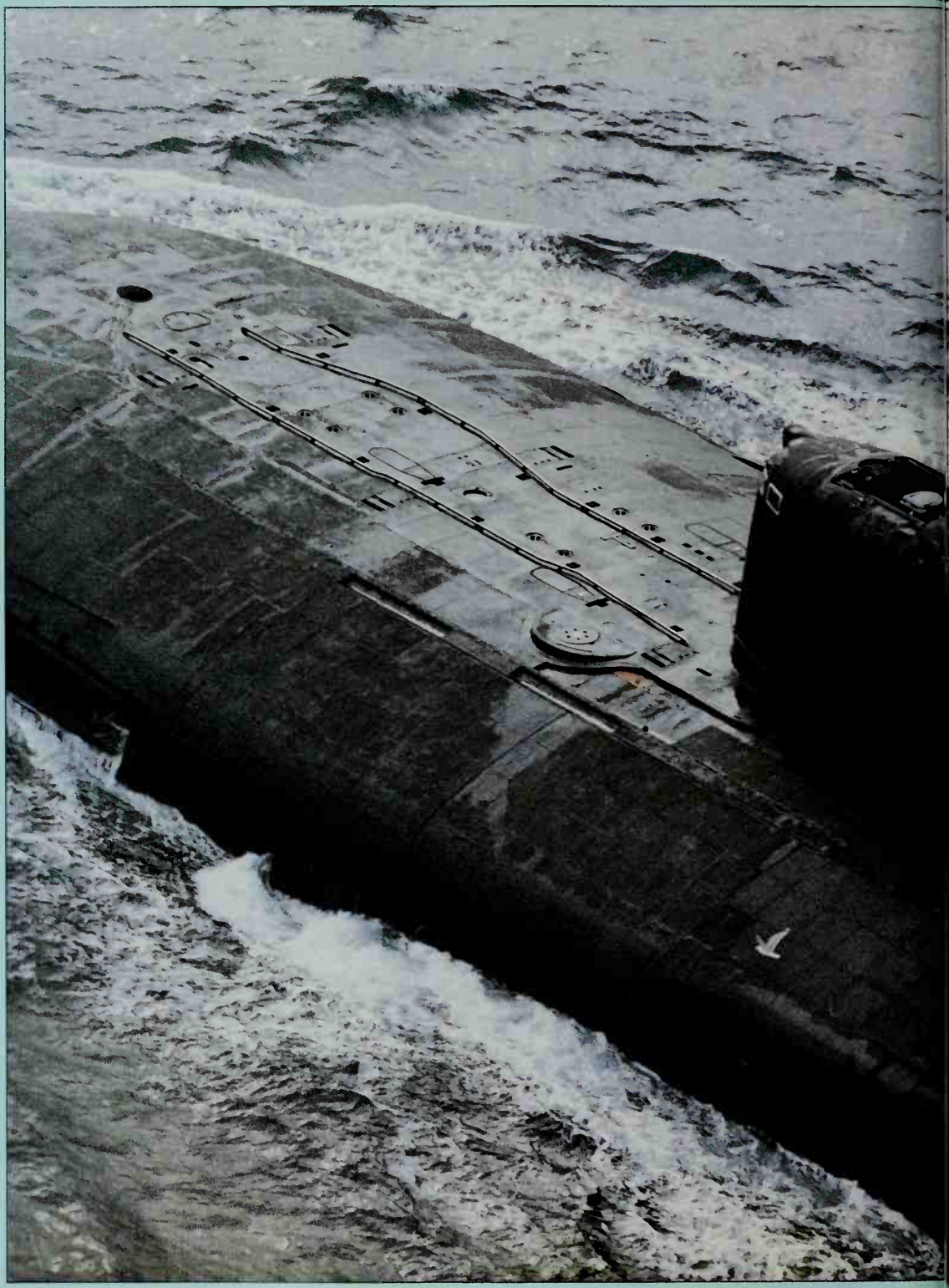
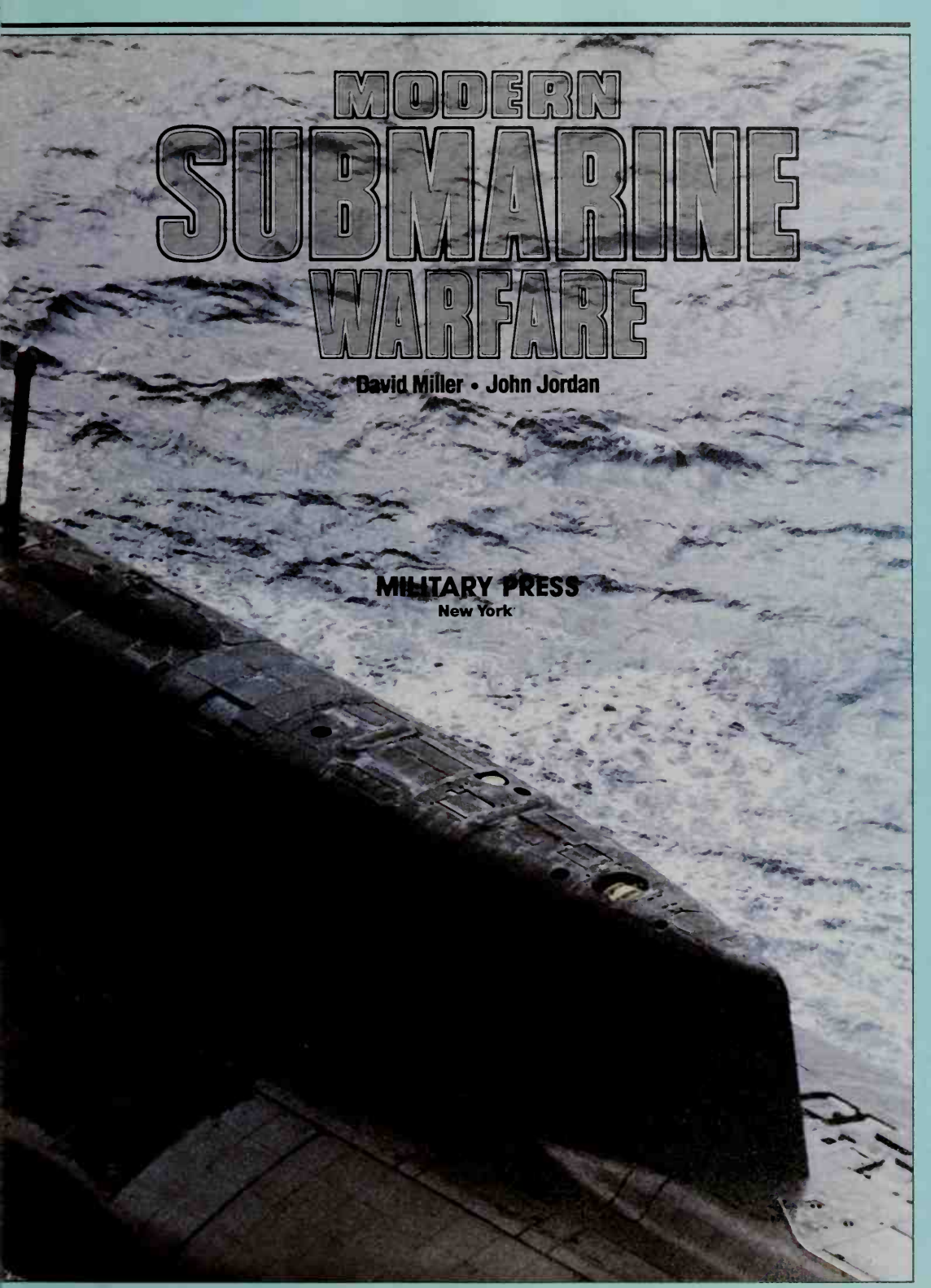
Above: The Oberon class submarine HMS *Opossum* under way in March 1984 after being refitted with the new Type 2051 bow sonar.



Above: The broad beam of this Soviet Oscar class submarine houses 12 SS-N-19 cruise missile tubes on each side of the sail.



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David Miller • John Jordan

MILITARY PRESS
New York

A Salamander Book Credits

This 1987 edition published by Military Press,
distributed by Crown Publishers, Inc.
225 Park Avenue South
New York, New York 10003

© Salamander Books Ltd., 1987

ISBN 0-517-64647-1

All correspondence concerning the content of this volume should be addressed to Salamander Books Ltd., 52 Bedford Row,
London WC1R 4LR, United Kingdom.

h g f e d c b a

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Editor: Bernard Fitzsimons

Designers: Mark Holt, Nigel Duffield

Colour artwork: Tony Gibbons, Terry Hadler, Janos Marffy, Maltings Partnership, Stephen Seymour, TIGA

Diagrams: TIGA

Filmset by Rapidset & Design Ltd.

Colour reproduction by Melbourne Graphics

Printed in Singapore

Acknowledgements: The publishers wish to thank wholeheartedly the many organizations and individuals in the defence and naval construction industries, and the armed forces of various nations, who have supplied photographs and information used in the compilation of this book. Sources of individual photographs are credited individually at the end of the book, but particular thanks are due to David Foxwell of *Naval Forces*. The diagrams appearing on pages 46-49 are based on information in *General Oceanography* by G. Dietrich and K. Kalle (Willey-Interscience, New York); *Fundamentals of Ocean Acoustics* by L. Brekhovskikh and Yu. Lysanov (Springer, Berlin, 1982); *Sound Propogation in the Sea* by Robert J. Urick (DARPA/US Government Printing Office); and *Underwater Acoustics Handbook II* by Vernon M. Albers (Pennsylvania State University, 1965).

The Authors

David Miller is a serving officer in the British Army, a career which has taken him to Singapore, Malaysia, Germany and the Falkland Islands and which has included service in the Royal Corps of Signals, several staff jobs at Army headquarters and the command of a regiment in the UK. He has contributed numerous articles to technical defence journals on subjects ranging from guerilla warfare to missile strategy and is the author of *An Illustrated Guide to Modern Submarines* (1982) and *An Illustrated Guide to Modern Subhunters* (1984), co-author of *Modern Naval Combat* (1986) and a contributor to *The Vietnam War* (1979), *The Balance of Military Power* (1981) and *The Intelligence War* (1983), all published by Salamander Books.

John Jordan is well known for his contributions on modern ships and submarines to journals such as *Navy International*, *Warship*, *Defence* and *Jane's Defence Weekly*. His work for Salamander includes authorship of the Illustrated Guides to *The Modern US Navy*, *The Modern Soviet Navy*, *Modern Naval Aviation*, *Battleships and Battlecruisers* and *Modern Destroyers*, and he was contributor to *The Balance of Military Power*.

Below: The Trafalgar class nuclear powered attack submarine HMS *Tireless* caught by the camera while running on the surface in November 1985.

Contents

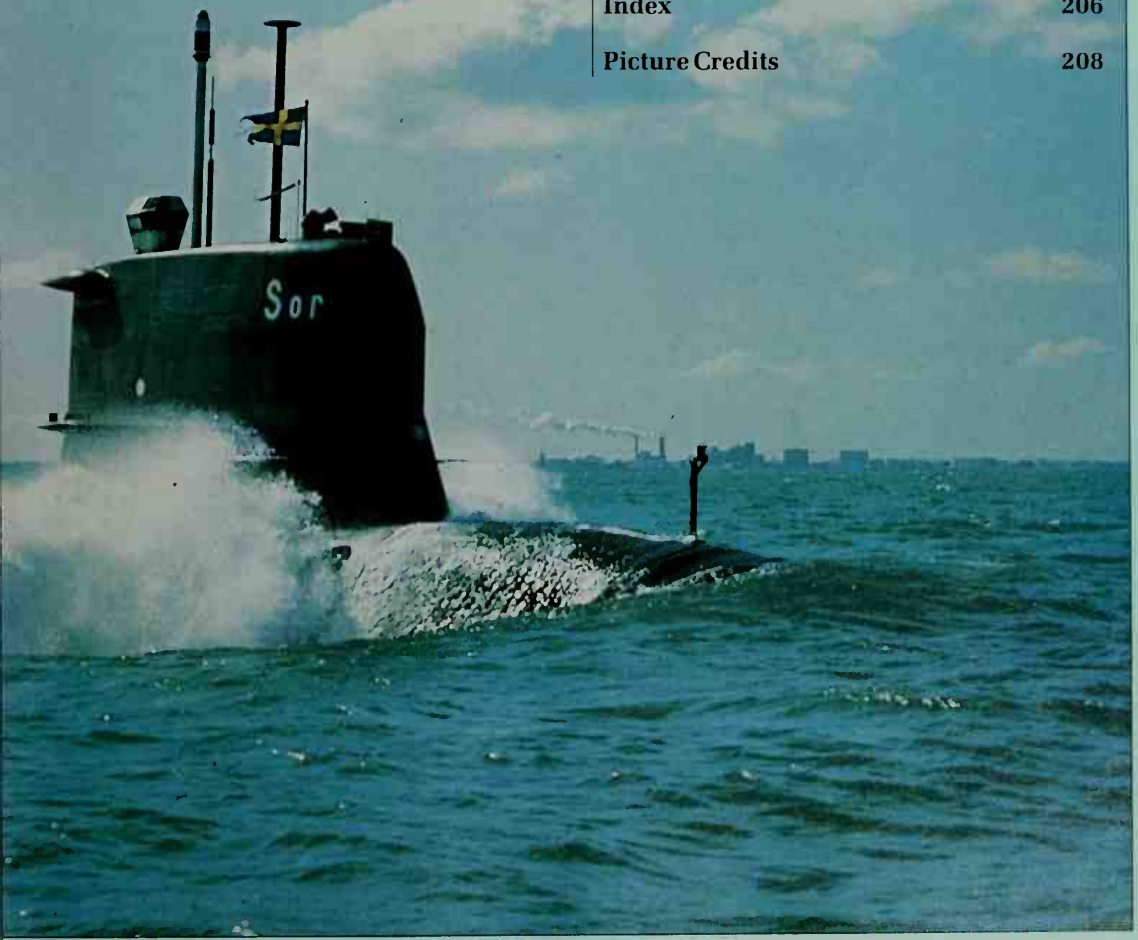
Foreword	**8**
Modern Submarine Technology	**10**
Introduction	12
Submarine Types	14
Milestones	26
The Oceans	44
Design and Construction	50
Propulsion	60
Weapons	64
Sensors	76
Communications	80
Surface Antisubmarine Warfare	84
Accidents and Rescue	96
Submarines and their Weapons	**100**
Introduction	102
Agosta class	104
Alfa class	106
Charlie class	108
Daphné class	110
Delta class	112
Echo II class	114
Foxtrot class	116
Golf class	118
India class	120
Juliett class	122
Kilo class	124
Lafayette class	126
Le Redoutable class	128
Los Angeles class	130
Näcken class	132
Nazario Sauro class	134
Oberon class	136
Ohio class	138
Oscar class	140

Permit class 142
Resolution class 144
Romeo class 146
Rubis class 148
Sierra class 150
Skipjack class 152
Sturgeon class 154
Swiftsure class 156
Tango class 158
TR-1700 160
Trafalgar class 162
Type 206 164
Type 209 166
Typhoon class 168
Upholder class 170
Valiant class 172
Victor class 174
Yankee class 176
Yuushio class 178
Zeeleeuw class 180

Underwater Warfare Tactics 182
Introduction 184
Submarine Tactics 186
Antisubmarine Tactics 194

Index 206

Picture Credits 208



Below: The Swedish submarine *Sjöormen*, name ship of a class of five 1,125-ton diesel-electric Albacore-hulled submarines launched in the late 1960s.

Foreword

For the first fifty years of its existence the submarine was a vessel which travelled and fought primarily on the surface, retiring under water only to hide or when under attack. Even when it submerged it did not go deep; indeed, it was not until the mid-1940s that submarines could dive to a depth greater than their own length. Sonar was an imprecise instrument and anti-submarine weapons were fairly ineffective, but a major problem for the submarine was the considerable speed advantage held by surface ships. During World War II the development of ship and aircraft radar forced submariners to spend longer below the surface, and while the invention of the schnorkel tube gave them a means of recharging their batteries at periscope depth their mast heads were still detectable, both visually and by radar. World War II also saw the appearance of the specialised anti-submarine aircraft as a particularly dangerous foe for the submarine, whether submerged or on the surface.

Freedom from regular forays to the surface for life support and propulsion came with the nuclear-powered steam plant, which gave endurance effectively limited only by human psychological and physiological factors and produced a truly underwater weapon system, capable of world-wide deployment and able to operate at fleet speeds with surface task groups. It also enabled submarines to travel submerged at speeds at least equal to those of attacking surface vessels.

Until the 1950s submarines' primary strategic role was against surface warships and seaborne logistic traffic. In both World Wars Germany brought the United Kingdom to the brink of starvation by attacking the supply routes across the Atlantic and in the second the US Navy won a great underwater victory against the Japanese, sinking millions of tons of shipping. The role still exists, but the evolution of submarine-launched ballistic missiles and, later, cruise missiles has brought a further and even more important strategic role, that of striking at targets in the enemy's homeland. Indeed, no spot on Earth is now beyond the reach of a submarine-launched weapon.

The USSR, while developing ballistic missile submarines like those of other nations, has also paid great attention to cruise-missile submarines intended primarily to counter US Navy carrier groups. The Americans, on the other hand, have avoided the need for such specialised boats by developing missiles – Tomahawk and Sub-Harpoon – which can be launched from either standard 21in torpedo tubes or from vertical launch tubes mounted between the submarine's outer casing and its pressure hull.

Top: The Los Angeles class nuclear-powered attack submarine USS *Birmingham* (SSN 695) surfaces in spectacular fashion. Nuclear propulsion has freed submarines which make use of it from the need to surface.

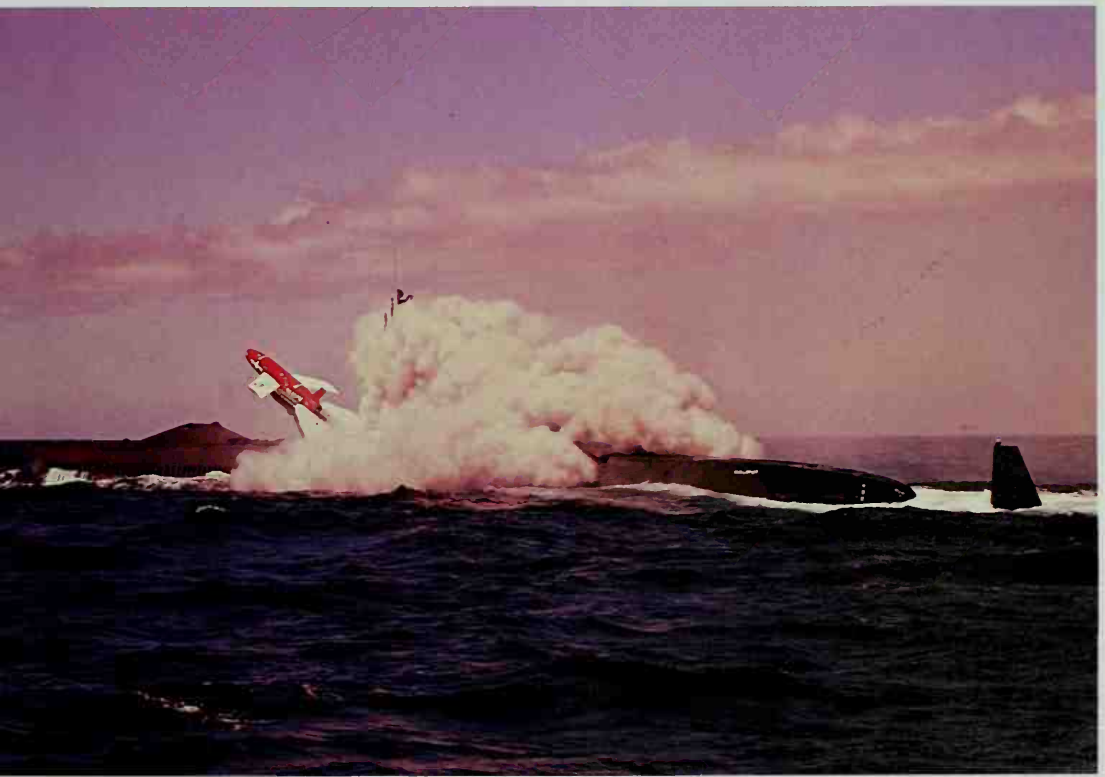
Above: There continues to be a big demand for conventional diesel-electric submarines: among the latest is the Indian Navy's HDW Type 1500, of which S45, seen here on builder's trials, is the second to be delivered.

Finally, the conventional diesel-electric submarine continues to thrive, and many hundreds are operational with 39 navies. Very few countries can afford the increasingly expensive nuclear powered boats; for Japan, the political implications of nuclear power are insuperable; and only the French and US navies have opted for all-nuclear underwater fleets.

Although submerged submarines are difficult to locate, all underwater craft give both acoustic and non-acoustic indications of their presence and there is no such thing as an undetectable submarine. Many countries are conducting expensive research programmes aimed at making detection of their submarines more difficult. Here NATO has long possessed a definite advantage since Soviet submarines are inherently noisier, so NATO forces should be able to detect and identify the enemy first. Early confrontations of a possible future conflict are secretly rehearsed every day: Soviet hunter-killers endeavour to track Western ballistic missile boats, NATO surface task groups practise anti-submarine techniques against tracking Soviet submarines and, as the incident of the Soviet Whiskey class submarine grounding off the Swedish Karlskrona naval base in November 1981 showed, clandestine reconnaissance missions do take place, though their frequency can only be guessed at.

The value and importance of the modern submarine was underlined during the South Atlantic War of 1982: after HMS Conqueror became the first nuclear-powered submarine to sink a surface warship when she attacked and sank the Argentinian cruiser General Belgrano the threat from the British submarines was so powerful that no further surface unit of the Argentinian Navy left coastal waters to threaten the British fleet. The Argentinian Navy, however, had submarines of its own and its West German-designed Type 209 diesel-electric submarines were a major threat to the Task Force throughout the campaign, especially to the aircraft carriers.

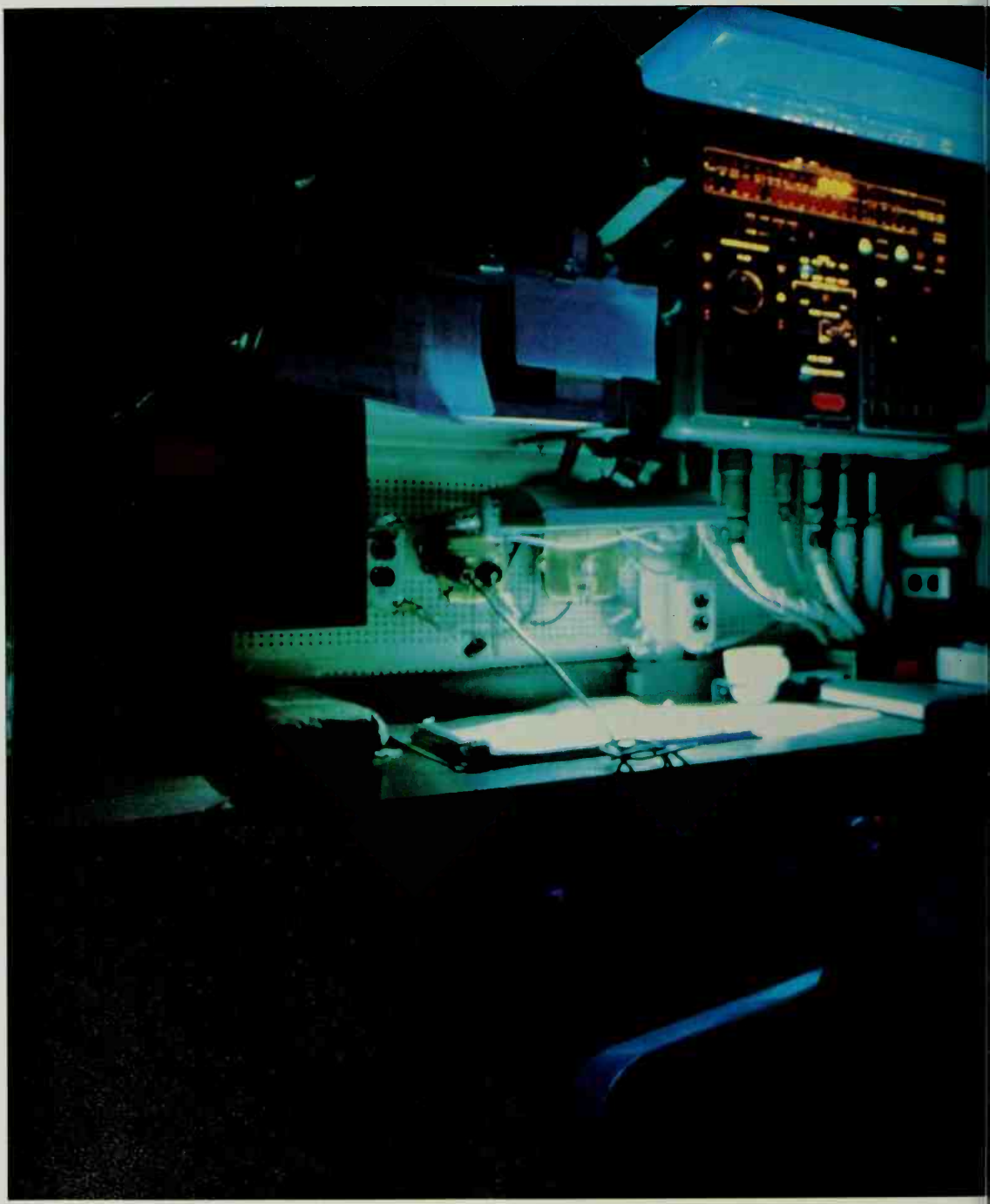
The modern submarine is difficult to find, identify and sink. It has a global capability, and in its current role the ballistic missile submarine is the ultimate deterrent, for its missiles threaten the enemy's cities and population in a counter-value role, while its inherent survivability gives it a virtually guaranteed second-strike role. The oceans of the world are now designated 'Inner Space', being so vast and unexplored and of ever greater economic value. It could well be that the military battle for control of this difficult and alien environment is only just beginning, and that the real age of the submarine is only now beginning to dawn.



Left: The bow and fin of a Soviet Tango class submarine. The Tangos are diesel-electric counterparts of the Victor class, the first Soviet nuclear-powered attack submarines, and are equipped with a large bow sonar and six or eight torpedo tubes able to fire torpedoes or SS-N-15 antisubmarine missiles. The 19 Tangos built before production was terminated in favour of the Kilo are stationed with the Northern and Black Sea Fleets.

Above: The first use of submarines as carriers of strategic nuclear weapons involved a couple of American World War II diesel electric submarines converted to launch Regulus cruise missiles. The only nuclear-powered cruise missile carrier built for the US Navy was USS *Halibut* (SSGN 587), completed in 1960 and seen here launching the RGM-6 training version of Regulus I. The Regulus II programme was cancelled in 1959.

Modern Submarine



Technology

David Miller

Below: Subdued lighting aids the hushed concentration of technicians monitoring the sonar console of the Los Angeles class attack submarine USS *La Jolla*.

Introduction

The remarkable range of submarine designs currently at sea is displayed in the central section of this book: the range of sizes, and the number of variations on a fundamentally cylindrical shape, is a reflection of the different roles for which they have been designed and the technological and economic resources available to the customer navies for which they were built. This section of the book describes and illustrates the various factors which bear on modern submarine design, and explains the characteristics that determine the modes of employment outlined in the final section.

As the brief historical survey with which the section opens shows, the relatively short history of the modern submarine has encompassed many strands of development, but the overall thrust remains clear. To survive a submarine depends on stealth, and as the performance of acoustic and other sensors improves, the ability to remain under water as long as possible, and the need to make as little noise as possible while there, are paramount. The latest developments in such areas as water-jet propulsion are highly classified, like many aspects of submarine design and operations, but the constraints of security still permit a reasonable survey of current technology.

In terms of construction there have been few dramatically new developments since the appearance of the teardrop-hulled *Albacore* in the early 1950s, though variations such as multiple pressure hulls and improvements such as anechoic hull coatings continue to crop up. The same is true of propulsion, with nuclear propulsion having conferred a startling increase in operational flexibility on those navies in a position to make use of it, but the rest having to be content with enhancements to the time-honoured combination of electric batteries charged by diesel generators for underwater propulsion. However, Swedish experiments with the closed-cycle Stirling propulsion system, which involves transferring the heat from burning fuel to helium enclosed in a working cycle of pistons and cylinders, separated by heater, regenerator and coding units continue to hold out hopes of advances in this area.

Weaponry is a different matter. Microprocessors have had an enormous impact on the capabilities of all modern weapons and their associated fire control systems, and not only has the traditional weapon of the submarine, the torpedo, been given entirely new autonomous homing capabilities, but whole new classes of weapon have become available, so that the modern attack submarine, exemplified by the Los Angeles class, has the ability to launch attacks with a range of missiles against land as well as the traditional surface and sub-surface targets at ranges far beyond those of the most advanced torpedo. And in the strategic arena submarines have become the repositories of the ultimate deterrent, since they would expect to survive a nuclear first strike that would attempt to neutralise land-based ballistic missiles and air-launched strategic weapons.

THE WORLD'S SUBMARINE FLEETS – JANUARY 1987

Country	SSBN S	SSBN B	SSGN S	SSGN B	SSB S	SSB B	SSN S	SSN B	SS S	SS B	SS R	Totals	Remarks
Albania									3			3	Soviet Whiskey (3)
Alberia									2			2	Soviet Romeo (2)
Arbentina									4	2		4	West German Type 209 (2), Type 1400 (2+2)
Australia									6			6	UK Oberon (6)
Brazil									7	3		7	UK Oberon (3), US Guppy (4), West German Type 1400 (3 on order)
Canada									3			3	UK Oberon (3)
Chile									4			4	West German Type 1300 (2), UK Oberon (2)
China	2	2			1		3	1	102		6	108	Most SS of Soviet design but all others of Chinese design
Colombia									2			2	West German Type 209 (2)
Cuba									3			3	Soviet Foxtrot (3)
Denmark									4			4	West German Type 205 (2), Danish Delfinen (2); 3 Type 207 may be bought from Norway
Ecuador									2			2	West German Type 209 (2)
Egypt									7			7	Soviet/Chinese Romeo (8), Soviet Whiskey (3)
France	6	1			1		2	3	13			22	All of French design and construction. No more non-nuclear submarines to be built
West Germany									24	12		24	Type 206 (18), Type 205 (5); 12 Type 211 on order
Greece									10			10	West German Type 209 (8), US Guppy (2)
India									8	7		8	Soviet Foxtrot (8); 4 West German Type 1500, 3 Soviet Kresta on order
Indonesia									3			3	West German Type 209 (2), Soviet Whiskey (1); order for third Type 209 postponed
Israel									3			3	West German Type 206 built in UK by Vickers (3)
Italy									10	2		10	Nazario Sauro (4+2) Enrico Toti (4), US Tang (2)
Japan									14	4		14	Yuushio (6+4), Uzushio (7), Asashio (1); all of Japanese design and construction
North Korea									21			21	Soviet Romeo (17), Soviet Whiskey (4); 18 midget submarines also in use as special forces transports
Libya									6			6	Soviet Foxtrot (6), Six Yugoslav midget submarines also in use as special forces transports
Netherlands									7	3		7	Zeele (2+3), Zwaardvis (2), Dolfijn (3); all of Dutch design and construction
Norway									14	6		14	West German Type 207 (14); 6 West German Type 210 on order
Pakistan									6	2		6	French Agosta (2+2), Daphne (4); also 2 midget submarines
Peru									12			12	West German Type 209 (6), US-built Dos de Mayo (4), US Guppy (2)
Poland									3			3	Soviet Whiskey (3)
Portugal									3			3	French Daphné (3)
South Africa									3			3	French Daphné (3)
Spain									8			8	Agosta (4), Daphné (4); Spanish-built to French designs. Next class may be nuclear-powered.
Sweden									12	4		12	Näcken (3), Sjöormen (5), Draken (4); 4 Vastergötland on order; all Swedish designed and built
Taiwan									2	2		2	US Guppy (2); 2 modified Dutch Zwaardvis on order
Turkey									17	7		17	West German Type 209 (5+7), US Guppy (10), US Tang (2); 7 Type 209 building in Turkey
USSR	64	4	49 +16 SSG		15		81	?	147	?		372	See separate table
United Kingdom	4	4					14	5	15	1		33	See separate table
USA	36	6					96	19	4			134	See separate table
Venezuela									3			3	West German Type 209 (2), US Guppy (1)
Totals	112	17	65		17		196	28+	517	51+	6	907+	

S = in service; B = building; R = reserve

MAJOR SUBMARINE FLEETS

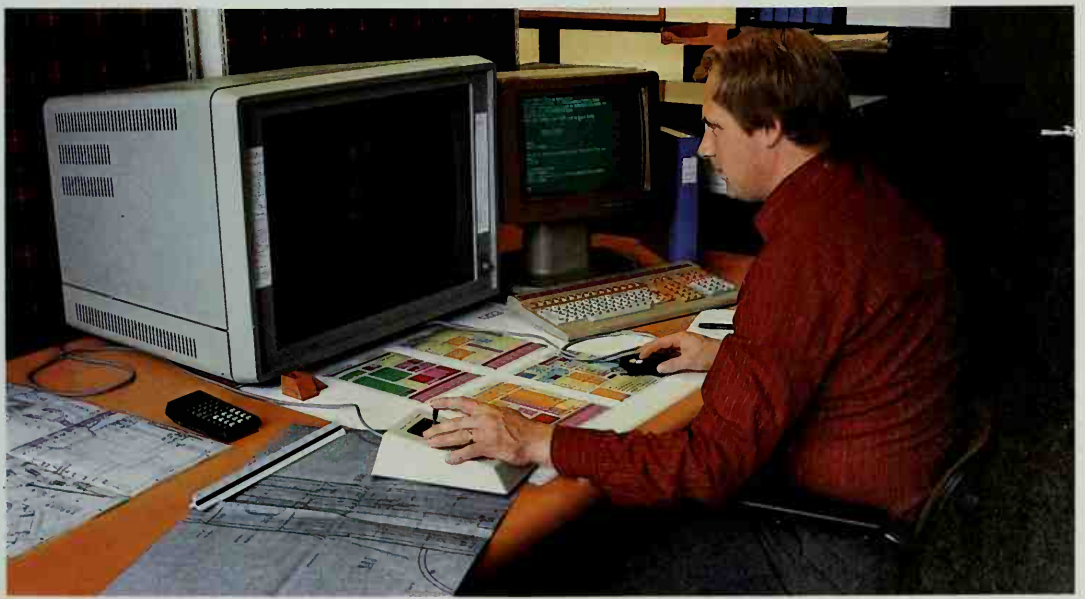
	USSR	S	B	USA	S	B	UK	S	B
SSBN	Typhoon	4	?	Ohio	6	6	Resolution	4	
	Delta IV	1	3	Lafayette	30		Vanguard		4
	Delta III	14							
	Delta II	4							
	Delta I	18							
	Yankee II	1							
	Yankee I	21							
	Hotel III	1							
	Totals	64	?		36	6		4	4
SSB	Golf V	1							
	Golf III	1							
	Golf II	13							
	Total	15							
SSGN	Oscar	2	?						
	Papa	1							
	Charlie II	6							
	Charlie I	11							
	Yankee	1							
	Echo II	8							
	Totals	49	?						
SSS	Juliett	16							
	Total	16							
SSN	Akula	1	?	Los Angeles	33	(+19)	Trafalgar	3	5
	Sierra	1	?	Lipscomb	1		Swiftsure	6	
	Mike	1	?	Bturgeon	37		Valiant	5	
	Alfa	6		Narwhal	1				
	Victor III	21		Parmit	13				
	Victor II	7		Tullibee	1				
	Victor I	16		Ethan Allen	2				
	Yankee	1	10	Shipjack	5				
	Echo	5		Skate	2				
	Hotel	1	4						
	November	12							
	Totals	72	?		95	(+19)		14	5
SS	Kilo	6	?	Barbel	3		Upholder	0	1
	Tango	19		Darter	1		Oberon	15	
	Foxtrot	58							
	Golf	3							
	Romeo	6							
	Zulu IV	2							
	Whiskey	55							
	Totals	162	?		4			15	1

Along with improvements to armament have come impressive enhancements to sensor and communications facilities – again largely based on the power of modern computers to process and display quantities of data that human being simply could not handle otherwise in any time frame that would enable tactical use to be made of it.

The consequence of all these improvements to the capabilities of modern submarines is that the resources devoted to antisubmarine warfare have also increased, and with naval weapon systems and platforms of every variety ranged against them, today's submariners must conduct their peacetime operations at a higher state of readiness than that applied in almost any other area of military activity. The day-to-day gathering of data on the performance and acoustic characteristics of hostile submarines is a fundamental part of the preparation for war in which navies are constantly engaged, which is why they are so reluctant to release more than the barest details of their performance and capabilities.

Finally, the hazards to which the crews of submarines are subjected cannot be overlooked by any navy which seeks to recruit personnel of suitable calibre and maintain a healthy level of morale, and the section concludes with a look at the modern rescue systems that would help crews survive in the event of an underwater accident, as well as some of the postwar disasters which have occurred.

Right: Submarines operate in three dimensions, and the forces ranged against them involve aircraft and surface ships as well as hostile submarines. This French Atlantic maritime patrol aircraft has flushed its target submarine to the surface.



Below: Computer-aided design is as important in the construction of modern submarines as electronic processing is in the operation of sensor and weapon systems. This design engineer is using a Kockums 3D CAD system to investigate mast arrangements.

Submarine Types

The submarine became a major factor in naval warfare during World War I, when Imperial Germany demonstrated its full potential for the first time after a long process of development by a variety of inventors and enthusiasts. A Dutchman, Cornelius van Drebel, is usually credited with building the first practicable submarine in 1620; he demonstrated his oar-powered craft in the Thames in London and even, so it is said, persuaded King James I to take a trip.

By the early eighteenth century numerous ideas for underwater craft had been patented, and during the American Revolutionary War the *Turtle*, a one-man submersible designed by David Bushnell, was used to attack the British man-of-war HMS *Eagle* in New York harbour. It was intended to attach a gunpowder charge to the ship's bottom with screws and explode it with a time fuze, but the attempt was unsuccessful. Robert Fulton designed a craft, the *Nautilus*, which he offered to France, Britain and the United States in 1801, but without any response.

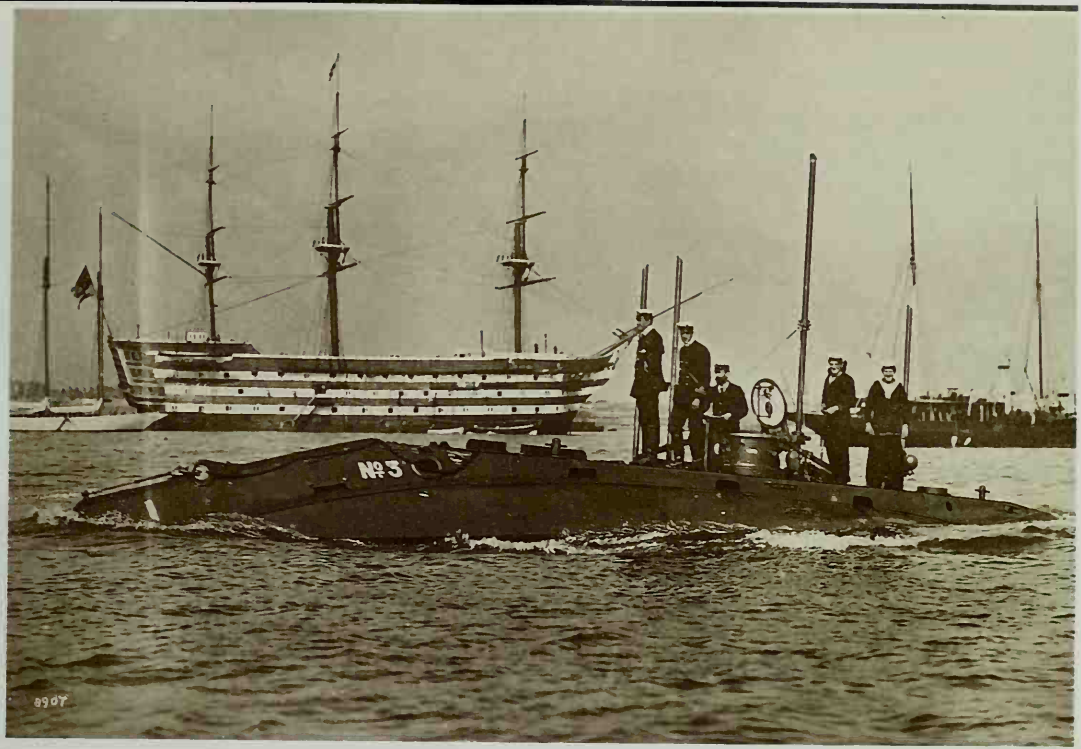
Several more submersibles appeared during the American Civil War and on February 17, 1864, a Confederate vessel, the CSS *Hunley*, sank the Federal Navy corvette USS *Housotonic* outside Charleston harbour. *Hunley* was driven by a screw propeller, turned by a hand-crank operated by a crew of eight men, and used a torpedo suspended ahead of her bow. As with the development of aircraft, which ran roughly parallel with that of the submarine, the problem of the submarine was not really soluble until a suitable means of propulsion was available. An English clergyman, the Reverend Barrett, successfully operated a steam-driven submarine, as did the Swede Nordenfeldt, but it was the electric motor which finally cracked the problem.

Credit for the first really effective submarine must go to J.P. Holland, of New Jersey, whose first boat was launched in 1875: many of his ideas are still in use today, notably the use of water ballast to submerge the vessel and of horizontal rudders to dive. The *Holland*, launched on May 17, 1897, was 54ft (16.45m) long and was propelled by a gasoline engine on the surface and by electric motors run from storage batteries when submerged. Despite successful trials, a cautious US Navy did not accept such a revolutionary device into service until April 11, 1900, and she was subsequently commissioned on October 12, 1900, Lieutenant Harry H Caldwell, USN, commanding. The company which produced this boat, the Holland Submarine Torpedo Boat Company, was reorganised in 1900 to become the Electric Boat Company and is still producing submarines today as the Electric Boat Division of the General Dynamics Corporation at Groton, Connecticut.

Above: USS *Holland*, the US Navy's first submarine, accepted April 11, 1900. Armed with three torpedoes, 53ft 10in (16.4m) long and capable of 8kt surfaced, 2kt submerged, she had a crew of six.

Right: Commissioned in 1903, the Royal Navy's *Holland 5* was the last of her class. Vickers-built and virtually identical to the US Navy's Hollands she lies aground at Fort Blockhouse, Portsmouth.

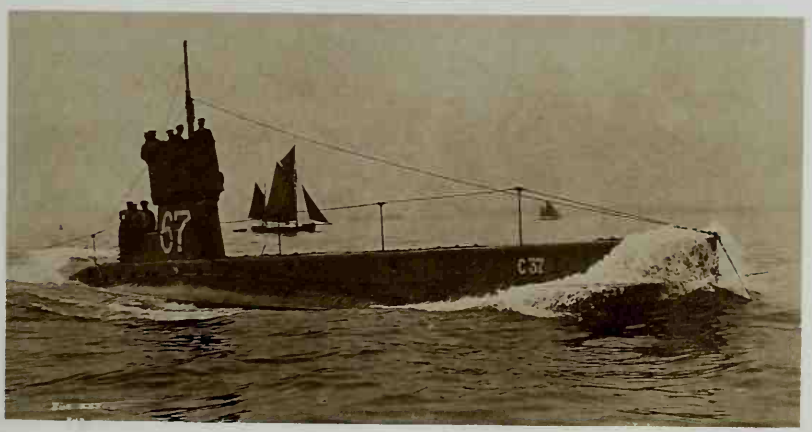
Below: The first of a long line of Royal Navy submariners, the crew of *Holland 1* adopt a stern and resolute mien for the camera. Presumably the seventh crew member took the photograph.



Above: The Royal Navy's *Holland 3* in pristine condition and with a very smart crew. Displacement was 104 tons surfaced, 150 tons submerged. These boats had one 14in (551mm) bow torpedo tube.

Left: The first British-designed boats, the A class (4 built), were succeeded by the 11-strong B class, built 1905-06. The latter were the first to be fitted with fore hydroplanes.

Below: The Royal Navy's fourth class of submarine, the 38-strong C class, had a displacement of 290 tons surfaced, 320 submerged, and two bow-mounted 18in (457mm) torpedo tubes.



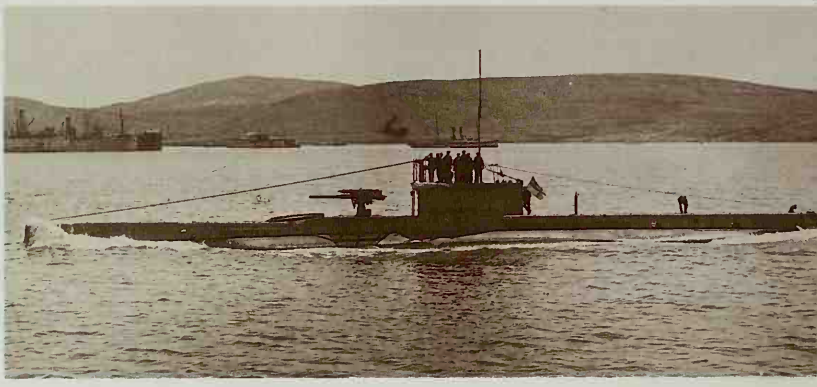
The French had long been interested in submarines, and a craft built in the 1860s, *Le Plongeur*, incorporated many excellent ideas. She was driven by an 80hp engine powered by compressed air stored in large steel bottles; the air was also used to blow the ballast tanks and to provide fresh air for the crew. Unfortunately *Le Plongeur* was very unstable and the French Navy failed to solve the problems of this very promising boat. A series of submersibles designed by Goubet were followed by the *Narval*, completed in 1899, which had steam and electric propulsion and good performance both on the surface and when submerged.

Once the feasibility of the submarine boat had been demonstrated by the Americans and the French, many navies became interested in the idea. The British Admiralty had watched progress with a mixture of scepticism and disdain, but by 1900 it felt compelled to become involved: development started with five Holland boats built in England by Vickers who, like Electric Boat, are still producing submarines today. *Holland 1* displaced 104 tons surfaced and 122 tons dived and had a crew of seven men; its speed was eight knots surfaced and five submerged. The five *Hollands* were followed by 13 A class (completed 1903-05), 11 B class (1905-10), 38 C class (1906-08) and eight D class (1908-11) boats, and the first of the very successful E class were just

joining the fleet by August 1914, when World War I started: the Royal Navy had by far the largest submarine fleet in the world, some 74 boats strong.

World War I saw submarines being used from the very start, with Kapitän-Leutnant Wedigen of the Imperial German Navy scoring an astonishing success on September 22, 1914, when he torpedoed and sank three British heavy cruisers. British submarines were very successful throughout the war, but it was the Germans who first used the submarine as a strategic rather than a tactical weapon. In attempting to seal off the transatlantic trade routes they sank a huge tonnage of Allied shipping, almost succeeding in their aim.

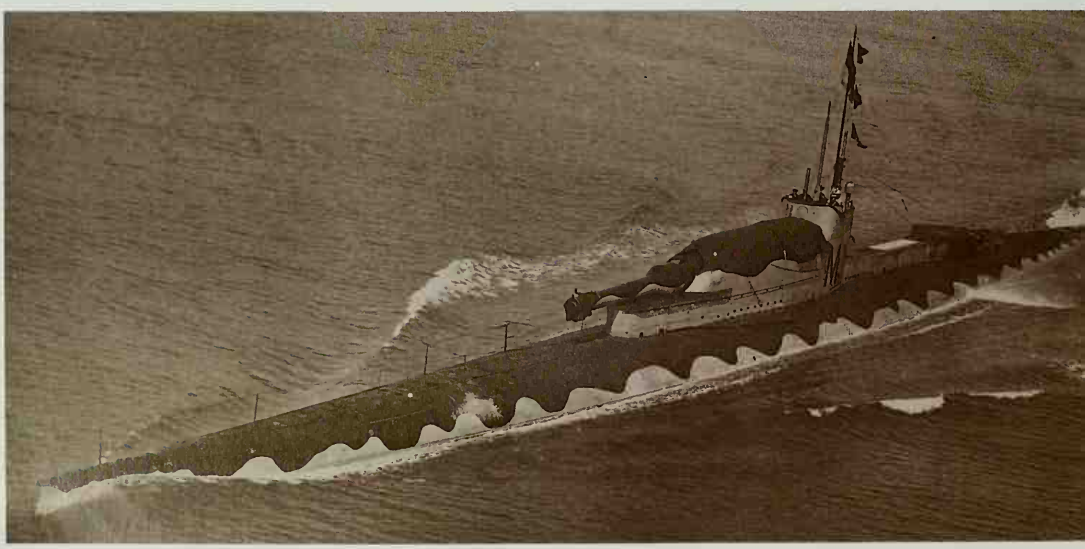
The submarines in use at the end of World War I were essentially bigger versions of those in service at the start of the conflict. Armed with torpedoes, plus guns for

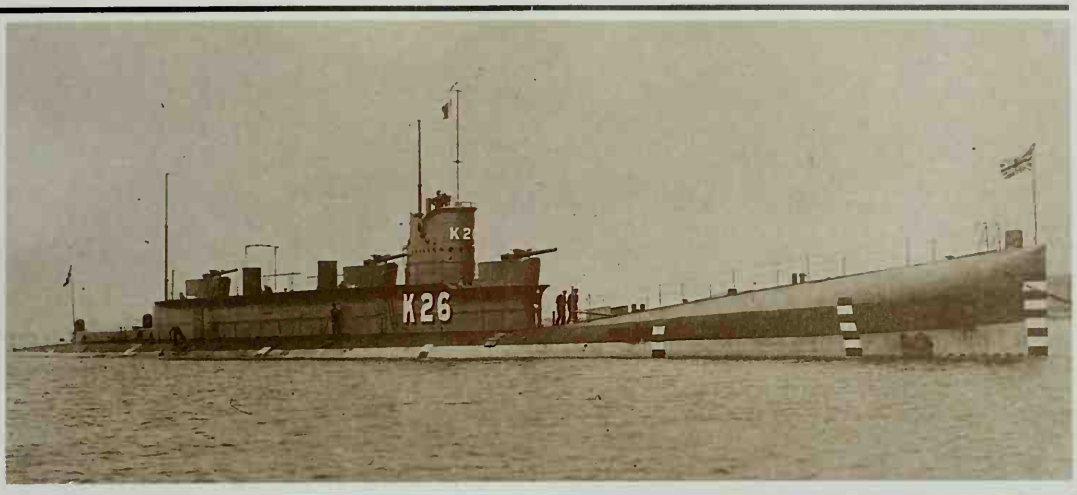


Above: HM Submarine *H.2* in Mudros Harbour in May 1916, during the ill-fated Dardanelles campaign. The first 20 were built in the USA to the American Holland class design and another 25 were constructed in the UK during the years 1915-19. The first boats to be armed with the 21in (533mm) torpedo tubes, they saw service in both World Wars, the last two being scrapped in 1945.

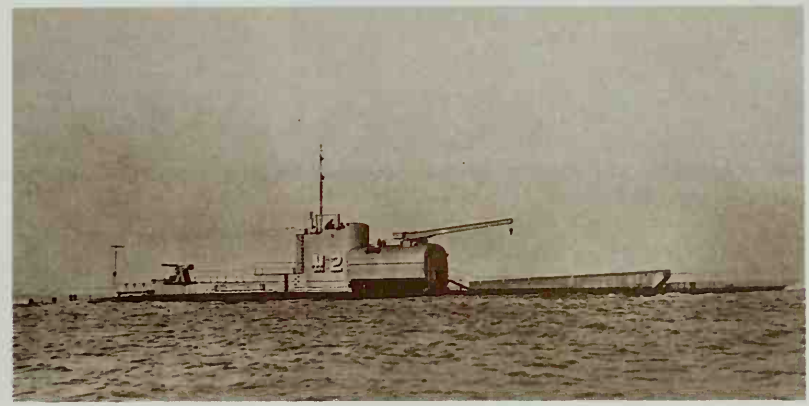
Above: Electric welding for hull construction was first used in the US Navy's two-boat Cachalot class – this is USS *Cuttlefish* (SS 171) – built 1931-34. This saved weight, added strength and solved the long-standing problem of oil-fuel leakage, which not only reduced range but also left a tell-tale oil slick on the surface.

Below: The Royal Navy's HMS *M.1* was armed with a 12in gun and four bow-mounted 18in (457mm) torpedo tubes. The gun had to be loaded on the surface, then the muzzle was blanked off before diving; when a target came in range she broached until the muzzle was clear of the water before opening fire.





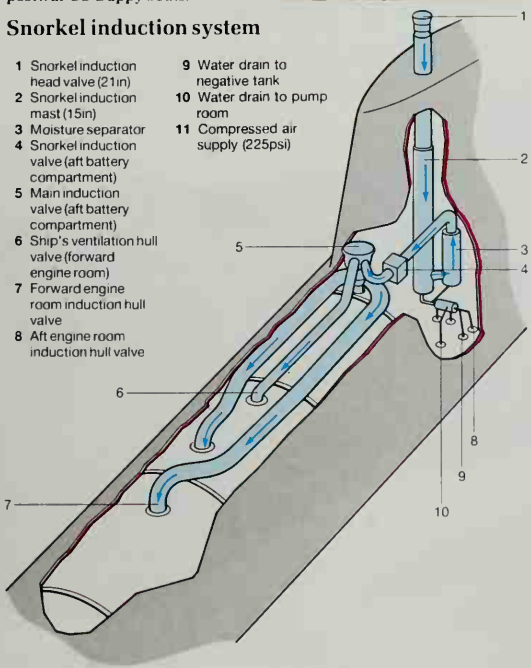
Above: Steam turbine-powered for a surface speed of 24 knots, the British K-class was designed to work with the fleet. *K.26*, a bigger boat than her sisters, completed a round trip to Ceylon in 1924.



Right: The British *M.2*, originally identical to the M.1 (opposite), had her gun removed and was converted to a submersible seaplane carrier. She sank in 1932 when the hangar was left open.

Below: A major step in diesel-electric submarine design was the snorkel tube, which enables boats to travel with just the head of the tube exposed while diesels are run to recharge the batteries. This diagram shows the system used on postwar US Guppy boats.

Snorkel induction system



surface action, they were capable of limited forays under water and were propelled by diesel-electric power. The Germans were already planning to take the war to the coasts of the USA and were building large 'cruiser' submarines as the war ended: *U-135*, for example, had a displacement of 1,175 tons surfaced and 1,534 tons submerged, and was armed with a 150mm gun and six 20in torpedo tubes; with a crew of 46 men she had a speed of 17.5 knots on the surface and 8.1 knots submerged.

The inter-war years saw slow but steady development of the patrol types. The German Type IXA of 1940 had a displacement of 1,032 tons surfaced and 1,153 tons submerged, and was armed with six 21in torpedo tubes and a 104mm gun. With a speed of 18.3 knots on the surface and 7.7 knots submerged she offered little additional capability and performance over the *U-135* of 22 years previously, although reliability and habitability were obviously much better.

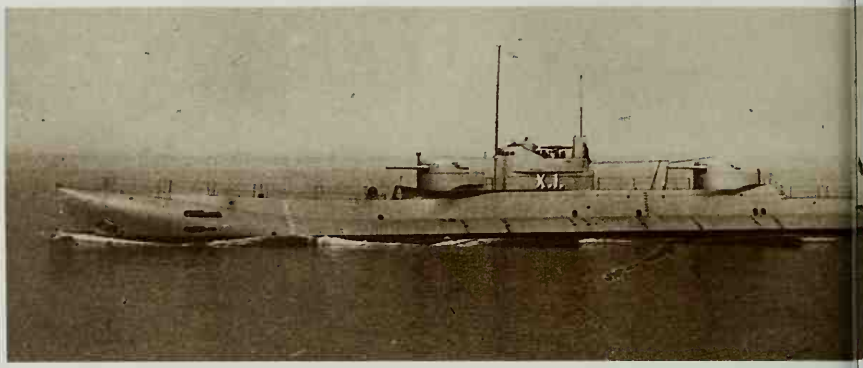
The years 1918-39 had also seen some unusual submarine developments, though the vast majority proved worthless. The use of guns appeared to offer some advantages over torpedoes and the British developed a series of submarines (K, M and X classes) in which guns were the principal weapons, while the French produced the mighty *Surcouf* (4,304 tons submerged) with two 8in guns in an immense turret forward of the conning tower. Experiments were also conducted with aircraft-carrying submarines by the British, French and Japanese navies but with very limited success.

World War II saw two great submarine campaigns, the first in the Atlantic, where German submarines again tried to cut off the United Kingdom from North America and again failed, and the second in the Pacific, where the US Navy set out to destroy the Japanese merchant fleet and succeeded. Much new equipment for submarines was introduced, notably radar, sonar, electronic warfare devices such as radio direction finding, and the snorkel. Speed, meanwhile, increased remarkably little: the US Navy's Balao class of 1943 had an underwater speed of just 8.7 knots, only marginally better than that of World War I submarines.

There were, however, three very significant breakthroughs, the first being the German discovery that by

streamlining the hull, doing away with all unecessary protuberances and increasing battery power, much greater speeds and endurance could be achieved. These refinements, coupled with that of the snorkel, resulted in the first boats to be more at home under the surface than above it and led to a programme of new boats or radical changes to old ones in virtually every navy.

The second great development was that of the tear-drop hull, pioneered by the US Navy's experimental submarine USS *Albacore*, which made submarines capable of much greater underwater speeds and solved the control problems, besides giving much greater internal space. The third was the perfection of nuclear propulsion, which – for the navies that could afford it – made submarines totally free of the surface for protracted periods.



THE OCEAN

Submarines must operate in a three-dimensional environment with a nature and properties all its own, one which we are only now beginning to understand. The ocean is fundamentally hostile to human beings, who can only exist there if they carry with them a part of their normal atmosphere, and has a behaviour pattern of its own, which is so far as unpredictable as atmospheric weather was before the advent of satellites.

The nature of the oceans pervades every aspect of submarine and anti-submarine warfare and leads to some very curious situations. A surface warship, for example, may detect a submarine some 30 miles away only to be sunk by a submarine just one mile away whose presence its sensors had been totally unable to detect. And just as sound behaves in an odd way, so too do explosions.

One example of the latter phenomenon occurred during World War II, when some British midget submarines were being towed across the North Sea to attack the German battleship *Tirpitz*. One of them, X-8, sprang a leak in her starboard detachable side-cargo (which contained the explosives), and this was jettisoned, exploding a few minutes later whilst still comparatively close; it did no damage to either X-8 or the towing submarine. Some time later the port side-cargo developed a similar problem and was also released, but this time the fuze was set for a two-hour delay: the fuze worked perfectly 120 minutes later, but the explosion caused such severe damage to X-8 that she had to be

German Type IXB U-boat

Origin: Germany
Type: Patrol submarine, diesel-electric powered
Displacement: 1,051 tons surfaced; 1,178 tons submerged
Dimensions: Length 251ft (76.5m); beam 22ft (6.8m); draught 15.7ft (4.7m)
Propulsion: Two 2,000hp MAN diesel engines, two 500hp electric motors for 18.2 knots surfaced; 7.3 knots submerged; 8,700nm at 12 knots surfaced; 64nm at 4 knots submerged; design diving depth 492ft (150m)
Complement: 48
Background: The Types I and II were training boats and were followed by the two types which bore the brunt of the U-boat war: the Types VII and IX. The Type IX was derived from the Type I, which itself had been derived from the U-81 series of 1916. Intended for distant water operations the Type IX had longer range, greater displacement and much better habitability than the Type VII: a double hull design was used and part of the 154 tons fuel load and all the ballast tanks were located between the hulls. Surface range was 10,500nm at 10 knots.

The Type IXB had a 165-ton fuel load, giving a range of 12,000nm, while the Type IXC and C-40, built in larger numbers than any other version, utilised yet more space between the hulls to house even more fuel (208 tons and 214 tons respectively) giving still greater range (12,000 and 12,300nm).

The D series boats were a major redesign, being 36ft (10m) longer and with yet further increases in range and speed. Two boats of Type IX-D1 were built, each having six high-speed 1,500hp diesels of a type normally fitted in motor-torpedo boats, giving a maximum surface speed of 21.8 knots. This installation, however, proved to be dangerous and unpleasant for the crew, and the idea was dropped after one operational cruise. The original engines were replaced by two of the usual MAN U-boat diesels, the torpedo tubes removed and they were then used as transport and refuelling boats, carrying 252 tons of fuel (in addition to their own 203 tons).

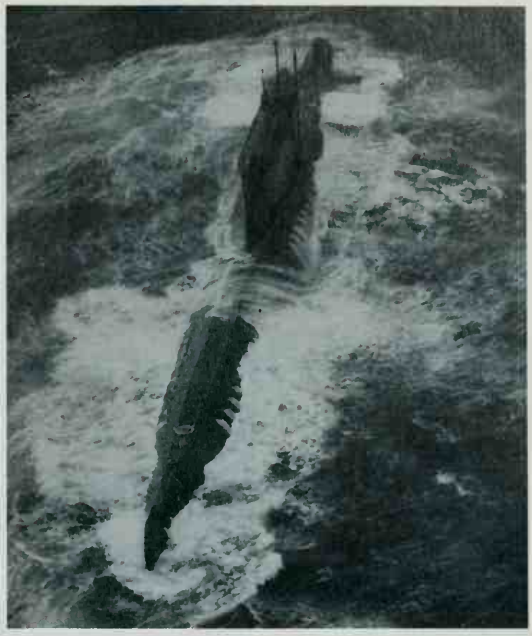
Types IX D2 and D-42 were designed for operations in the South Atlantic and Indian Oceans and their maximum fuel load of 441 tons gave them an incredible surface range of 31,500nm at 10 knots, and a maximum surface speed of 19.2 knots. Many D2s carried Focke-Achgelis FA-330 single-seat autogyros, which could be towed by the submarine at a height of some 300ft (100m) to enhance surface surveillance capability. They had a surface range of 23,700nm at 12 knots. Some IXD boats were used for importing vital stores from Japan and some were used as submarine tankers, most of which were lost. 29 Type D2 were built and two Type D-42, but it was then decided to switch production to the Type XXI.

Many Type IX boats were fitted with snorkel tubes from 1943 onward, and radar and DF antennas were also fitted. As a result top weight increased, as did crash-diving time, which had originally been 35 seconds. Part of the weather deck was removed from some boats, which reduced the number of spare torpedoes.

Below: The Type IXA mounted two periscopes, but all later models were fitted with three. Electronic sensor devices were fitted in increasing numbers as the war progressed. The threat from ever more effective, radar equipped Allied ASW aircraft was countered by a succession of detectors, including, the FuMB29 (Bali), which was later replaced by the FuMB10, a more capable, wide-band set. U-boats were also fitted with their own radars, including FuM029 and FuM030. U-862, one of the boats which went to Malaya, was fitted with FuMG200 'Hohentwiel', a set developed from a Luftwaffe ship-detection set.

Left: The 1915 Admiralty Submarine Development Committee proposed several disastrous concepts, among which was the idea for this X-class 'cruiser'. X.1, the only example built, weighed 3,585 tons submerged and was armed with four 5.2in guns in two turrets plus six 21in (533mm) torpedo tubes. She was laid up in 1930.

Right: The Soviet Hotel class nuclear-powered ballistic missile submarines, of which nine were built before construction was terminated in 1960, were the first SSBNs in service. This example is seen off Newfoundland after an accident in 1972.



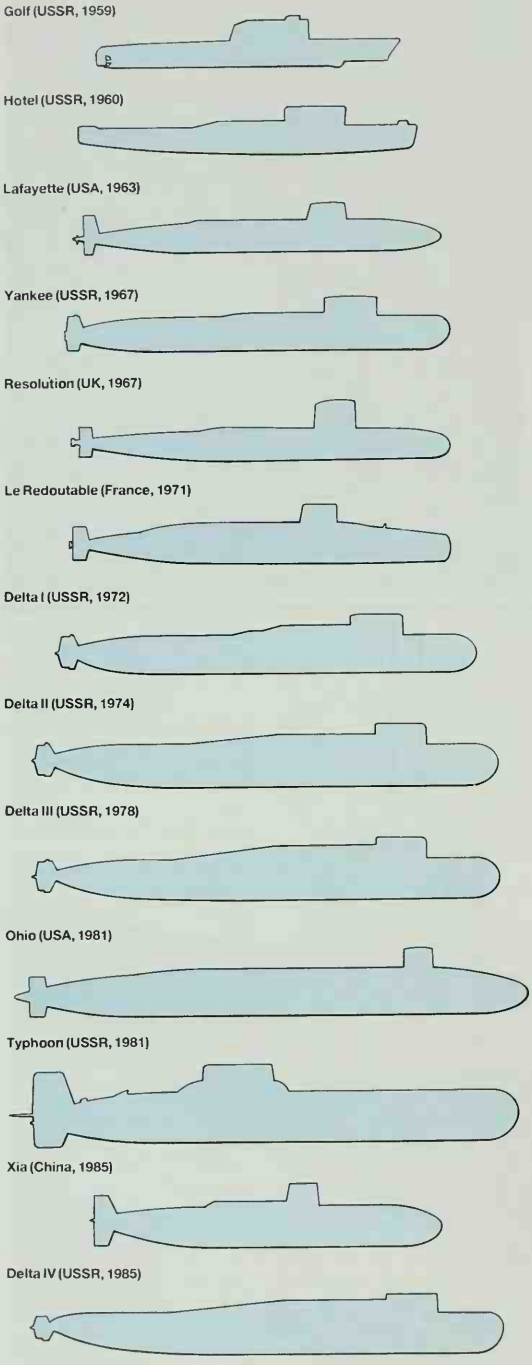
abandoned. The charges were identical, but the detonation of one at a few hundred yards did no damage at all, while that at a distance of a little over three miles caused a great deal of damage, entirely because of the curious nature of the sea.

BALLISTIC MISSILE SUBMARINES

The first true ballistic missile submarines were those of the Soviet Navy's diesel-engined Golf class, with three SS-N-4 missiles mounted vertically in the fin. The subsequent Hotel class also had fin-mounted missiles, and it was not until the appearance of the Yankee class in 1966 that the Soviets had a purpose-built SSBN equivalent to those in the West. Even so, the Yankee I had the SS-N-6 missile with a comparatively short range, which meant that the boats had to deploy close to the US mainland to obtain

Above and left: The Type IXB had a single 105mm gun on the foredeck, one 37mm anti-aircraft gun on the afterdeck and one 20mm AA gun mounted on a platform at the rear of the conning tower. From 1944 the 105mm and 20mm weapons were replaced by two twin 20mm. All versions had six 21in (533mm) torpedo tubes, four bow-mounted and two stern-mounted, with 16 reloads; the standard torpedo carried was the G7E.

Ballistic missile submarines in service



Above: SSBN classes currently in service, shown by the date of completion of the first example. The earliest Soviet boats, the Golf and Hotel classes, have their missiles mounted vertically in the sail, but all the rest carry their primary armament in the hull abaft the sail, except for the Typhoon, in which the tubes are forward. The inexorable growth in submarine size is clear.

Above: A Soviet Delta takes a buffeting while running on the surface in the North Atlantic. The size of the missile compartment is dictated by the length of the SS-N-8 missiles.

Right: The Ethan Allen class were designed as SSBNs from the outset; this is USS *John Marshall* (SSBN 611). The earlier George Washingtons were lengthened versions of the Shipjack class.

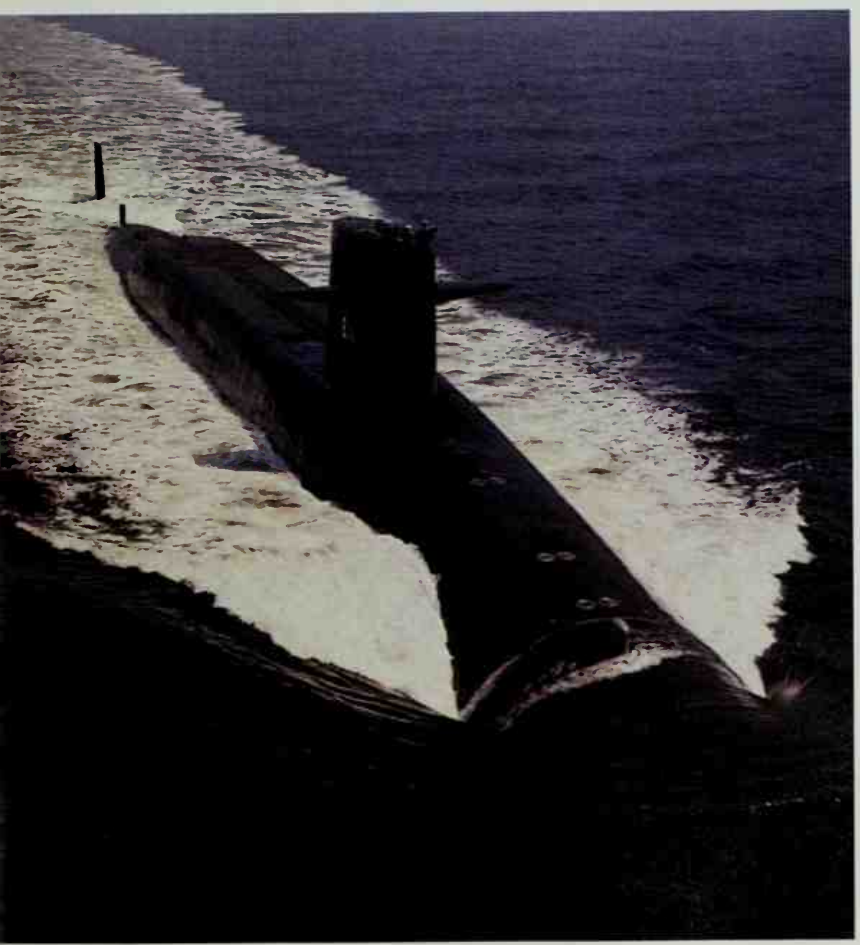
good coverage of targets such as SAC bases.

Yankee numbers are declining as boats are converted to other roles to keep within the SALT II limits, and the sole Yankee II carries the experimental SS-NX-17, but the next class, the Delta, is now in its fourth major modification – Delta I had 12 SS-N-8, Delta II 16 SS-N-8, Delta III 16 SS-N-18 and Delta IV 16 SS-N-23 – having grown in the process from 10,000 tons submerged (Delta I) to 13,600 tons (Delta IV). The latest Typhoon class (29,000 tons) boats carry 20 SS-N-20 missiles ahead of the fin.

Soviet SSBN design tended to lag behind that of the West for some years, with much evidence of very hasty conversions in the early types. Even in the recent Deltas the ungainly whaleback necessary to accommodate the large missiles is very poorly matched to the fin, which will undoubtedly give rise to much underwater noise at any speed. The Typhoon is an interesting design which has been discussed at length in the West: the consensus view is that it is constructed of two parallel hulls joined together and surrounded by an elliptical outer hull – it is even suggested that the hulls may simply be two Yankee or Delta hulls suitably modified – which should make for a very spacious interior which could be used for extra crew, longer patrols, additional equipment or an esoteric propulsion system.

The Typhoons appear to have been designed specifically for

Above: Artist's impression of the British Vanguard class SSBN designed for the Trident missile, the first of which was laid down at the Vickers Yard in Barrow. A major national debate has raged within the UK about the wisdom of adopting the Trident system, with each of the major political parties taking a different stance on the issue. Four are planned and a fifth is unlikely.



under-ice deployment, and one example has demonstrated an ability to launch at least four ballistic missiles simultaneously, whereas all other ballistic missile submarines fire their missiles in a "ripple", which could take as much as 15 minutes in the case of the older types, and during which they are very vulnerable; thus, to fire salvos is a major change. One interesting note is that the first commanding officer of the first Typhoon was awarded a very high decoration at the end of his tour of command – so high and rare, indeed, that he was the first recipient since World War II.

The US Navy has just three classes of SSBN in service: 31 of the virtually identical Lafayette and Franklin classes, of which 12 have 16 Trident I missiles while the remainder retain their 16 Poseidons, and an increasing number of the Ohio class, which mount 24 Trident missiles abaft the fin. Unlike previous classes, the Ohios are powered by the S5G natural-circulation nuclear-reactor system, developed from that tested in the *Narwhal*.

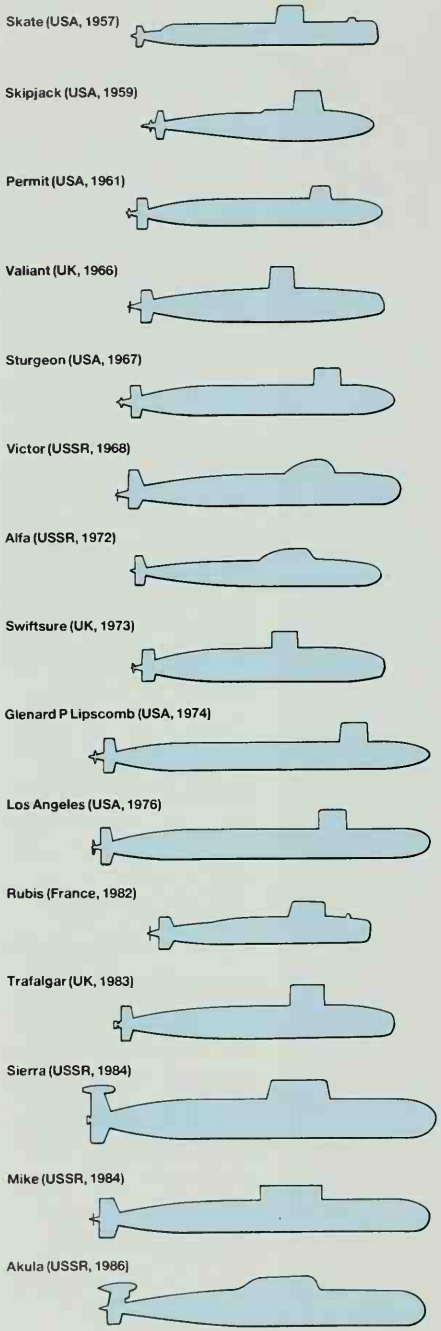
British and French SSBNs, like the Lafayette and Franklin classes, carry 16 missiles abaft the fin and are of similar size. The French have now produced six SSBNs, with a gradual improvement in each case, while the Royal Navy has not built any since the last of the four Resolutions was finished in the late 1960s. There will, therefore, inevitably be substantial changes in design in the four new British Trident boats, which will obviously incorporate the lessons learned from the SSN programme. Finally, China is building an SSBN fleet, with two boats of the Xia class operational by the end of 1986 and a further four to follow.

In design and operational terms the Yankee, Delta, Lafayette, Franklin, Resolution and Le Redoutable classes have a lot in common, and it is only with the advent of the Typhoon and Ohio classes that there has been a divergence. The Typhoon is huge and there seems no reason why next-generation Soviet SSBNs should not be even bigger if all they are required to do is to cover the relatively short distance to the Arctic ice-cap. The Ohio is a less radical design than the Typhoon and is, in effect, a logical progression of the Lafayette and Franklin classes – bigger, longer, quieter and with more missiles. Perhaps the most interesting developments are the Chinese boats and the new, much smaller nuclear reactor fitted in the French Rubis class SSNs, and it will be interesting to see the effect of the latter on the design of the next generation of SSBNs.

CRUISE MISSILE SUBMARINES

The Soviet Navy's submarine-launched cruise missile programme originated in the 1950s as a response to the threat posed by

Nuclear-powered attack submarines in service



Above: Nuclear-powered attack submarines (SSN) currently in service, arranged by date of completion of the first unit of the class and shown to the same scale as the ballistic missile submarine profiles on page 20 for comparison. Only the USSR can afford the resources to maintain two classes, Mike and Akula, in production. Mike is thought to serve as a propulsion testbed; Akula is similar to Victor III and Sierra classes. Insufficient data was available on the Chinese Han and Ming classes.

Above: The need to increase the range of submarines' weapons continued from the British *M.1* and *X.1* to this first missile boat, USS *Carbonero* (SS 337). The conversion was carried out under the Loon programme in the late 1940s, and involved the installation of a launch ramp for copied German V1 missiles. *Carbonero* was subsequently refitted for Regulus trials.

the US Navy's aircraft carrier task groups. Some crude conversions of Whiskey class patrol submarines were followed by the first purpose-designed classes, the nuclear-powered Echo class and the diesel-electric Juliett class. Twenty-nine Echo IIs, each armed with eight SS-N-12s, and 16 Julietts armed with four SS-N-3As each were still in service in mid-1987.

In both classes the missiles are mounted in bins stowed flush with the hull casings, and the bins are raised prior to launching on the surface. There are prominent indentations behind each launcher to act as blast deflectors, which generate a lot of underwater noise. The missiles are fired from ranges of about 200 miles, well beyond the normal ASW screen, but such ranges necessitate external assistance to achieve over-the-horizon targeting; initially this was provided by two Bear-D reconnaissance aircraft, but the difficulty of achieving coordination and the vulnerability of the aircraft made this a relatively ineffective system and it is believed that satellites are now used. A large radar is also needed on the launch submarine, the antenna for which – Front Door or Front Piece – is mounted at the forward end of the fin.

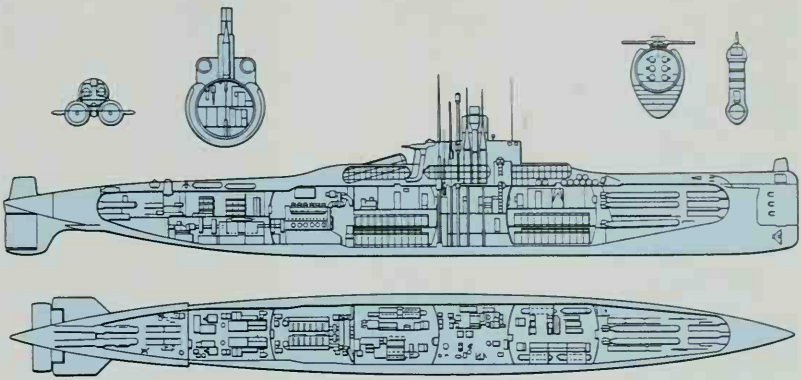
The first Charlie class SSGN appeared in 1968: smaller, quieter, faster and with much greater hydrodynamic efficiency than the Echo class, it fires its SS-N-7 missiles under water and does not need an aircraft in the control loop. Also, the missile bins are all mounted forward of the fin and flush with the hull. The later Charlie class boats have a lengthened bow section, suggesting that they may be fitted with the SS-N-15 ASW missile.

Next to appear was the Oscar class (18,000 tons), armed with 24

Below: Some US submarines were converted for cruise missiles, but USS *Halibut* (SSGN 587) was designed specifically for the task. The missile facilities were removed in the late 1960s and *Halibut* was used for DSRV trials.

Right: Soviet Navy Juliett class SSG, armed with four SS-N-3A cruise missiles. Sixteen of these boats were commissioned in the early 1960s and all still serve, six in the Baltic, the rest in the Atlantic and Mediterranean.

Chinese Type ES5G



Right: The Chinese export submarine Type ES5G is armed with six missile launchers mounted in pairs beside the sail. It also has six forward and two after torpedo tubes.

SS-N-19 missiles, huge submarines with the exceptionally wide beam of 60ft (18.3m). The missile bins are in the casing, but the great girth is probably due to the use of double hulls, making this design, like the Typhoons, very difficult indeed to destroy.

The Soviet Navy has developed an SLCM similar to Harpoon, which is launched from a standard 21in (533mm) torpedo tube and which will obviously be deployed on SSNs, but it would appear that they still intend to continue SSGN development. However, there appears to be no intention in any Western navy to produce a such a specialised type.

NUCLEAR POWERED ATTACK SUBMARINES

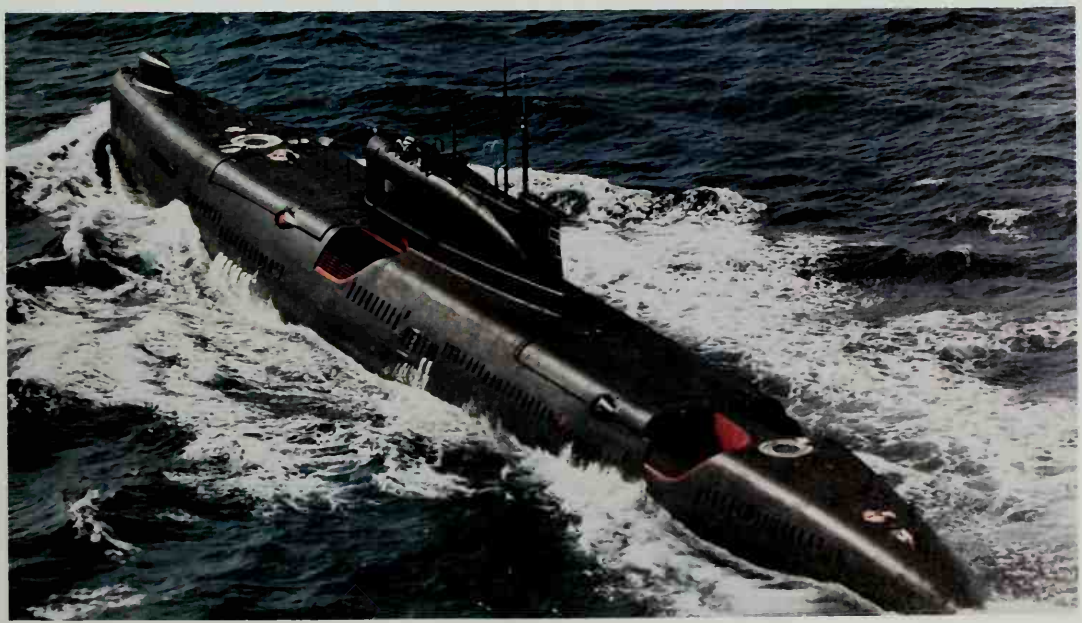
The oldest SSNs in US Navy service are the five Skipjacks, which are small and handy but lack advanced sonar systems. The Permit and Sturgeon classes which followed are larger, carry more sophisticated sonar outfits and fire Subroc, but with no increase in power the speed of these classes fell to 28 knots. The latest type of SSN in service with the US Navy is the Los Angeles class, which showed a 50 per cent increase in displacement over their predecessors. These boats are fitted with more advanced sensors and fire control equipment – both of which are now being retrofitted to the 14 Permit class and 37 Sturgeon class boats – but, in addition, the Los Angeles class restored the speed levels of the Skipjack class.

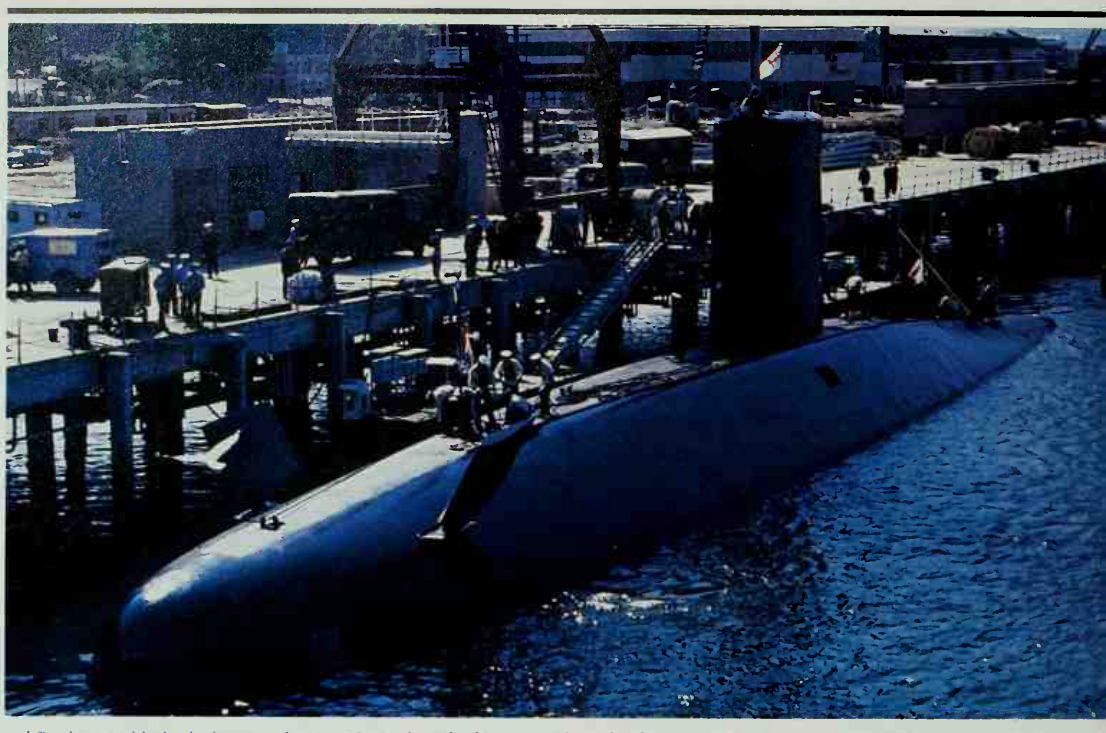
Soviet Navy operating procedures have in the past made it unlikely that there would be surface task groups against which US SSNs could concentrate, though with the advent of the Kiev and Kremlin class aircraft carriers and the Kirov class battlecruisers the Soviets seem to be generating such targets. US SSNs are therefore designed for three primary roles: anti-submarine hunter-killer, particularly in defence of ballistic missile boats; independent forward area attack and reconnaissance; and the protection of surface task groups and convoys.

Nuclear propulsion is a relatively noisy way of powering a submarine, particularly at high speeds, but successive US designs have shown a steady improvement in this respect. In the Los Angeles class particular attention has been paid to quiet operation, and the large hull makes it easier to cushion the machinery. The increase in speed also reflects the increasing tactical requirement for the defence of carrier task groups against Soviet SSGNs, and all US SSNs except the Skipjacks are being fitted with Harpoon missiles to give them a new capability against surface units.

The Soviet Navy still retains a number of elderly and unreliable November class SSNs in service, but its principal current type is the second-generation Victor, which has a much improved hull form, greater diving depth, a much quieter propulsion system and a submerged speed of about 30 knots. The 16 Victor Is were followed by six Victor IIs, 15.4ft (4.7m) longer and capable of carrying the SS-N-15. Then came the Victor III, longer still and with an unusual cylindrical object on top of its fin, which may be associated either with a towed array or an advanced propulsion system.

Finally, there are no fewer than three new types of Soviet SSN, the Mike, Sierra and Akula classes. The Sierra appears to be a logical development of the Victor III and the Akula seems to be yet a further development of that line, but the Mike has a somewhat different hull





Above: HMS *Dreadnought*, the first British SSN, was powered by a US S5W reactor while the first British powerplant was developed and tested at Dounreay. The boat was listed for disposal in 1982.

and fin shape and lacks the large bullet found on the vertical rudders of both the Sierra and the Akula classes.

The Royal Navy has produced a series of highly effective SSNs; *Dreadnought*, first of the line, has been retired, but all the others remain in service. The British SSNs are similar to the American types, but by no means identical: their main design features are that the hulls tend to be fuller and to taper at a greater angle at the stern than those of the US boats, and the forward hydroplanes are mounted at the bow rather than on the fin. A conformal sonar array is installed at the bow, rather than the US sphere, which allows the torpedo tubes to remain at the bow. The drive system on the latest Trafalgar class employs hydrojets rather than propellers to cut down on cavitation noises.

The French Rubis class SSNs are much smaller than other SSNs, which must be a result of a new type of small nuclear reactor, and there has been much speculation, but no confirmation, that such a size reduction has been achieved by the use of liquid-metal cooling. The actual design of the boat is not unusual, however, being basically a modified version of the Agosta conventional submarine design.

CONVENTIONAL SUBMARINES

Conventional submarines fall into three main categories, the first being the coastal or shallow-water submarine of 400-600 tons, epitomised by the German Type 205 and 206 and Italian Toti classes. These have proved effective little boats, but obviously suffer from limitations in range, torpedo reloads and sensor capacity.

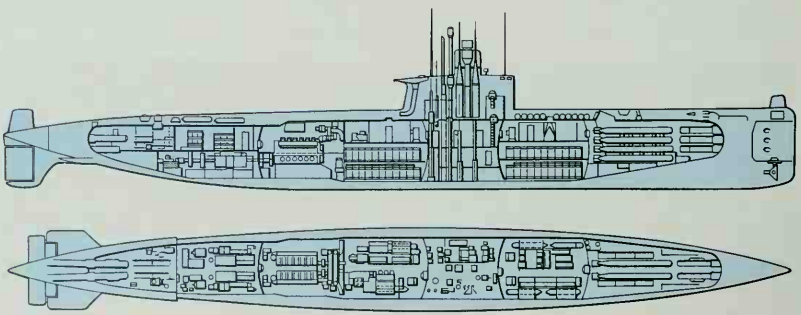
The 900-1,300-ton bracket includes the German Type 209, Yugoslavian Sava and Swedish Näcken and Sjörmen classes. These, too, are limited in endurance and carrying capacity and are to be found in the smaller navies with medium-range roles. It is, however, of interest that the Swedish Näcken class is one of the finalists in the Australian submarine competition. The majority of current types are of 1,600 tons or more and include the British Type 2400, Dutch Walrus and Soviet Foxtrot, Kilo and Tango, the last being the largest non-nuclear submarine at 3,700 tons.

In design terms there is no one design or nation that stands out as being significantly different from the rest, and clearly the operational requirements are remarkably similar in many respects. Of the three latest designs in the West, for example, the Japanese Yuushio is 249.25ft (76m) long with a surface displacement of 2,200 tons, while the figures for the British Type 2400 are 2,125 tons and 230.5ft (70.25m) and the Dutch Walrus 2,350 tons and 220ft (67m). All three types are armed with six 21in torpedo tubes and all have submerged speeds in the vicinity of 20 knots.

The number of countries capable of producing their own submarines is growing rapidly. The traditional manufacturers have been the UK, USA, USSR, France, Germany, Italy and Sweden, but these have been joined in recent years by Argentina, Turkey, Yugoslavia, Denmark, Spain, China and North Korea. And it is interesting that this is one area where the USA has no capability whatsoever. The last operational diesel-electric submarine built in a US shipyard

Below: The Chinese ES5E export model diesel-electric submarine is derived from the Soviet Romeo, produced in Chinese yards for many years. As with the ES5G (overleaf) this boat has two stern torpedo tubes in addition to the six bow tubes. When submerged the ES5E displaces 2,113 tons and has a maximum speed of 18 knots and an endurance on batteries of 330nm at 4 knots.

Chinese Type ES5E



Above: One of the major naval developments of recent years is the rapid spread in submarine manufacturing capability from the few countries to which it was formerly confined. Typical is this West German Type 209 design being built at the Golcuk Yard in Turkey. The cleanness of the hull, a major factor in the Type 209's exceptional quietness, is visible under the scaffolding.

Below: US Navy research sub *Dolphin* (AGSS 555), used in many experiments since 1969. Her pressure hull is a perfect cylinder, closed at each end by hemispherical bulkheads.

was the *Bonefish*, launched on November 22, 1958, and when there was a brief spate of interest in another conventional class in the late 1970s it was a West German yard that made the offer.

Conventional submarine development is currently at a very interesting stage, with many existing boats in several navies becoming due for replacement, notably the ex-US Balao, Tench and Guppy types, the British Porpoises and Oberons, the French Daphnes and the Soviet Whiskeys and Romeos. Available designs include the British Type 2400, French Agosta, Italian Sauro, Dutch Walrus, Swedish Näcken, and West German IKL and Thyssen designs, while further designs are in production but unlikely to be offered for sale abroad, including the Japanese Yuushio and Soviet Kilo and Tango classes.

OTHER SUBMARINE TYPES

Some navies have submarines for other purposes. Both the US and Soviet navies have submarines designated 'troop carriers,' which are clearly used for special forces – SEALs in the US case and Spetznaz in the Soviet. The US examples are two former Ethan Allen class SSBNs deactivated under the SALT II agreement, while the Soviet boats of this type are the newly completed first unit of the Uniform class and a converted Echo II. The USSR also has numerous small submersibles, at least some of which are tracked bottom-crawlers, used for Spetsnaz operations. Yugoslavia builds Mala class two-man midget submarines, of which they operate two themselves while Libya has six, and North Korea has 18 indigenously built midget submarines.

There are also a number of research submarines. The US Navy has the purpose-built *Dolphin* and nuclear-powered *NR-1* as well as using older submarines for research from time to time. The USSR follows the same pattern with at least one research boat of the Lima class, and a number of former front-line combat submarines of the Foxtrot, Zulu, Whiskey and Romeo classes used for various types of research.

Although submarines are now much safer and accidents much rarer than formerly, there is nevertheless a need for specialised rescue craft. The US Navy uses two Deep Sea Rescue Vehicles which are air transportable in C-141 Starlifter aircraft, and can be ferried to the scene of an accident by various US and British submarines. The Swedish Navy has a similar Swedish-designed vehicle, the URF, and the Italian Navy has its own Usel. As is to be expected, the USSR has a large variety of such vehicles, including two varieties which are transported to the deck wells on purpose-built India class submarine mother-ships.

Milestones

This book is not a historical survey of the submarine, but it is necessary for a proper understanding of present-day submarine technology to know a little about its development, examined here in terms of six submarines which are considered to be milestones in submarine design.

The British E class submarines were in service throughout World War I and were the immediate descendants of the original naval submarines, in turn developed from the Holland boats which were the first submarines to be true weapons of war. They are, therefore, taken to be archetypical of the first generation of true combat boats.

During the years between the world wars the development of the submarine proceeded at a slow, steady and unspectacular way, leading to the boats used by the navies in World War II, but there was a great deal of experimentation, mainly due to the disparity of views on the employment of the submarine in war. Having seen that a great deal of successful action by submarines had taken place on the surface using guns, there was a strong school which argued that large calibre guns should be carried and another that advocated the carriage of aircraft to provide the means for reconnaissance and gun spotting. Various heavy gun and aircraft-carrying submarines were constructed, but the only one to combine both features was the French Surcouf, the biggest submarine of its day.

Many excellent submarines were constructed by the navies involved in World War II, and there was steady development in many fields, particularly in diving ability and sensors. The US Navy's Gato class boats, which served primarily in the Pacific, are a good example of the culmination of the original line of slow, shallow-diving boats, still totally dependent on regular exposure on the surface to recharge the batteries – the last of the submersibles.

Above: *A.1*, the first British designed submarine. The A class, developed from the Holland, had a higher conning tower, a short periscope and a crew of 14. After a late start, by 1914 the RN had the world's largest submarine fleet.

All the World War II developmental lines came together in the Type XXI, which had a streamlined hull and fin, schnorkel tube, much reduced gun armament and greatly increased propulsive power and was the first of a totally new generation of true submarines and one which had a dramatic effect on post-war development.

Dramatic as they were, the improvements made by the Type XXI were all evolutionary, and two more fundamental developments were to come. The first was the new hull form introduced by the USS *Albocore*, a diesel-electric powered experimental submarine capable of 33 knots submerged speed. The second great step forward was the successful development of nuclear propulsion which, in conjunction with the carbon-dioxide scrubber, finally made the submarine independent of the surface.

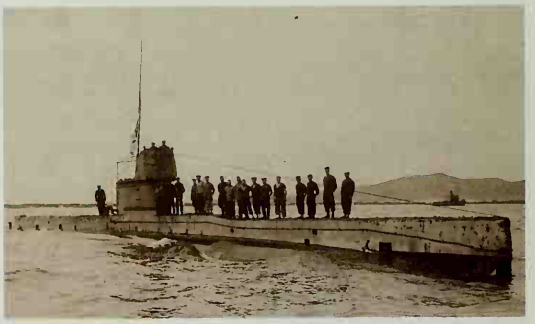
Above right: The D class, built 1908-1911, were the first British boats with diesel engines, twin screws, saddle tanks and radios. *D.4* was also first to mount a gun, although *D.8*, here entering Portsmouth harbour, had none.

Right: An unusual line-up representing the first five classes of British submarine; from the right, *A.5*, *B.1*, *C.35*, *D.2* and *E.1*. They clearly show the gradual increase in size and displacement from the 207 tons (submerged) of the A class to the 800 tons of the E class.

E Class

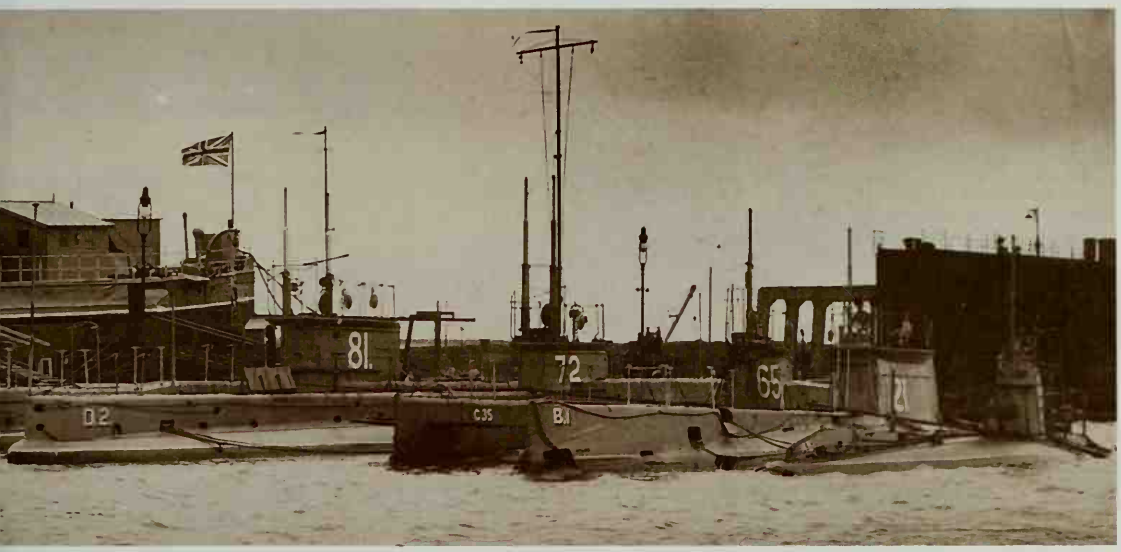
Origin: UK, first unit completed 1913
Type: Patrol submarine, diesel-electric powered
Displacement: 667 tons surfaced; 807 tons submerged
Dimensions: Length 181ft (55.2m); beam 22.5ft (6.9m); draught 12ft (3.7m)
Propulsion: (E.1 type) one petrol engine; one electric motor; 150bhp on one shaft; (E.7 and E.21 types) two Vickers 8-cylinder diesel engines, each 800bhp; two electric motors, each 420bhp; two shafts; (all) 16kt surfaced, 10kt submerged, 2,600nm at 10kt surfaced, 99nm at 3kt submerged; design diving depth 150ft (45.7m), crushing depth 350ft (106m)
Complement: 3 officers, 28 ratings
Background: The British E class, probably the first truly formidable and reliable submarines, were the outcome of a progressive development programme going back to the turn of the century. In the early days of submarine development the Royal Navy had monitored foreign progress closely and in 1900 negotiations were started for the successful Holland design that had just been tested in the USA. By 1914 Britain had the largest submarine fleet in the world, with 74 boats built, 31 under construction and a further 14 either projected or on order.

In 1900 the Royal Navy entered into a contract with Vickers to build submarines for the Royal Navy until 1906, later extended to 1912. The first boats, *Holland* 1-5, were similar to the American A class, but they were difficult to control both on and below the surface, and a modified and enlarged version was ordered. The first, *A.1*, was a great improvement, although the hull form was not particularly efficient and was improved in later members of the class, giving increased speed. Although more



Above: HM Submarine *E.2* on her return from a World War I patrol against Turkish targets on the Sea of Marmara. The E class boats had a distinguished war record, though they paid a heavy price for their success, 25 being lost and one interned.

Right: *E.14* leaves for the Sea of Marmara, where she was to sink three Turkish ships, in April 1915. Note the high-frequency radio antenna stretching from the bow to the top of the radio mast. E boats were the RN's major submarines during the war.



controllable than the *Hollands* they were still prone to dive without warning, and *A.8* was lost with all her crew after such an incident. Also, the use of petrol engines meant that vapour built up in the enclosed space of the hull, which led to several explosions. *A.13* was built with a Hornsby-Ackroyd heavy-oil engine; she was launched in 1905, but tests delayed her completion until 1908.

The A class was followed by the larger B and C class boats, both of which types had a surface displacement of 280 tons and the same armament as the A class, but with two sets of hydroplanes to improve controllability and more powerful machinery giving improved performance, while both habitability and range were improved. Ten B class and 37 C class boats were built. *D.1*, the first of eight D class boats, had a surface displacement of 550 tons and was fitted with Vickers machinery and

Above: HM Submarine *E.31*, one of two E class boats built by Scotts. Armament of the E class varied. *E.1-E.6* had four 18in (457mm) torpedo tubes, two in the bow and one on each beam, while the E.7 and E.21 types had an additional stern torpedo tube. Torpedoes were Mk 8s, with a maximum range of 6,000 yards (5,486m), although effective range was more like 3,000 yards (2,783m). All E class boats had a mounting for a gun; 6-pounder, 12-pounder and 4in weapons were fitted, though it appears to have been up to the captain whether or not one was actually carried. Shown here is the 12-pounder. Six boats were completed as minelayers with the two beam torpedo tubes replaced by mine tubes with a capacity of 20 mines.

Left: *E.47* clearly shows her shape, particularly the saddle tanks. A gun is mounted abaft the conning tower and the stern torpedo can just be seen above the men scrubbing the hydroplane.

twin screws. She also had much greater reserve buoyancy and an armament of three 18in torpedo tubes and a 12-pounder gun, but did not have the size and habitability for long-range work.

Design: The E class were enlarged Ds, being some 30ft (9.1m) longer and approximately 15in (38cm) wider, and were divided into three groups: the E.1 type (*E.1* to *E.6*, *AE.1* and *AE.2*), the E.7 type (*E.7* to *E.20*) and the E.21 type (*E.21* to *E.56*, less *E.28*, which was cancelled). The E class boats were built to an excellent design, and with their stronger hull and transverse bulkheads achieved new standards of integrity. They were the first British boats to have water-tight bulkheads, the early boats having two bulkheads, dividing the hull into three main compartments – fore-ends; control room and beam torpedo space; and engine-room, motor room and stern space – while later examples had three. All had 10-ton drop keels, which could be jettisoned from the control room in an emergency.

Like all early British submarines they could dive quickly, though they also exhibited a tendency to dive suddenly at high speed on the surface. Their Vickers solid-injection eight-cylinder diesel engines, though less sophisticated than contemporary German diesels, were extremely reliable for the time, and electric power for the two motors was provided by two 112-cell Exide batteries, each cell weighing 865lb (392kg). The batteries generated 220 volts/600 amps and could be connected into four 56-cell groups either in parallel at 110 volts or in series at 220 volts.

The E class was to have been succeeded by the G class, with a surface displacement of 700 tons, but the latter took longer to build and on the outbreak of war a further 20 E class were ordered to build up British submarine forces as quickly as possible. *E.1* to *E.18* had taken between 20 and 30 months each to build, but *E.19*, ordered in November 1914, took just eight months to build, fit out and hand over to the navy. Another two boats, *AE.1* and *AE.2* were built for the Royal Australian Navy.

E.22 was converted in 1916 to carry two Sopwith Schneider floatplanes, which were intended to bomb German Zeppelin sheds at Cuxhaven and Tondern and to shoot down Zeppelins on their way to bomb targets in England. Unlike later aircraft-carrying submarines, (such as the *M.2* and *Surcouf*) the aircraft were mounted in the open on rails on the afterdeck; there was no watertight container and so there was no question of the submarine submerging with the aircraft in position. Also, there was no crane and the aircraft were floated off and recovered by trimming down aft. This particular experiment appears not to have been a success, although a number of aircraft-carrying submarines were to appear in the 1920s and 1930s.

The E class boats had a distinguished war record in the North Sea, the Baltic and, particularly, the Dardanelles, where several broke through into the Sea of Marmara. The class was worked very hard throughout the war and the captains were nothing if not aggressive, winning a number of Victoria Crosses in the process. As a result 25 were lost during the war and one was interned in Denmark in 1915. All the remaining boats were paid off in 1921-22.

The E class was typical of World War I submarines, with an armament of one gun and a number of torpedo tubes. Indeed, no succeeding class until the arrival of the Type XXI was different in concept or in overall performance, the only increases being in size and range.

Armament: All E class submarines had either one six-pounder or one 4in gun and were the first Royal Navy production class to be so fitted. The original E.1 type had four 18in torpedo tubes, two in the bow and two in the beam (one on each side), spanning the bulged lateral tanks. The E.7 and E.21 types had an additional 18in (457mm) torpedo tube mounted in the stern, but the six boats completed as minelayers (*E.24*, *E.34*, *E.41*, *E.45*, *E.46*, *E.51*) had the two beam tubes replaced by mine tubes for 20 mines. The torpedoes were Mk 8s, which had a maximum range of 6,000 yards (5,486m), but by the time they had travelled that far their speed was down to about 29 knots. Running speed out to 3,000 yards (2,783m) was about 41 knots.

Construction: 57 E Class boats were built between 1913 and 1917, 55 for the Royal Navy and two (*AE.1* and *AE.2*) for the Royal Australian Navy. They were the first major class to be built in yards other than those of Vickers: Chatham Dockyard (6); Vickers (20); Beardmore (6); Yarrow (1); Armstrong Whitworth (4); Scotts (2); White (1); Thornycroft (2); John Brown (3); Fairfield (2); Cammell Laird (4); Swan Hunter (3); and Denny (3)

Surcouf

Origin: France, completed 1929
Type: Cruiser submarine, diesel-electric powered
Displacement: 3,252 tons surfaced; 4,304 tons submerged
Dimensions: Length 361ft (110m); beam 29.5ft (9m); draught 23.7ft (7.3m)
Propulsion: Diesel-electric drive on two shafts; two Sulzer diesel engines; two electric motors; 3,400shp for 18.5kt surfaced, 10kt submerged, 10,000nm at 10kt surfaced, 70nm at 4.5kt submerged; design diving depth 400ft (122m)
Complement: 118
Background: The search for a weapon with greater range and flexibility than the torpedo has continued almost since the inception of the submarine. For a long time attention concentrated on the only available alternative, the gun, and it was not until the 1960s that a really effective weapon, the submarine-launched cruise-missile, became available. The last, and arguably the epitome, of the gun-armed cruiser submarines, was the Surcouf.

Up to the beginning of World War I submarines had very limited capabilities, but as the war progressed there were great improvements in design and performance, until it appeared possible that submarines could become capable of more than just lying in wait for merchant ships and warships and attacking them with short-range guns or torpedoes. Obviously, a bigger gun would enable the submarine to attack surface targets at much greater ranges, but it was very difficult to acquire targets and estimate ranges from the relatively low conning tower, so several navies experimented with submarines equipped to operate aircraft.

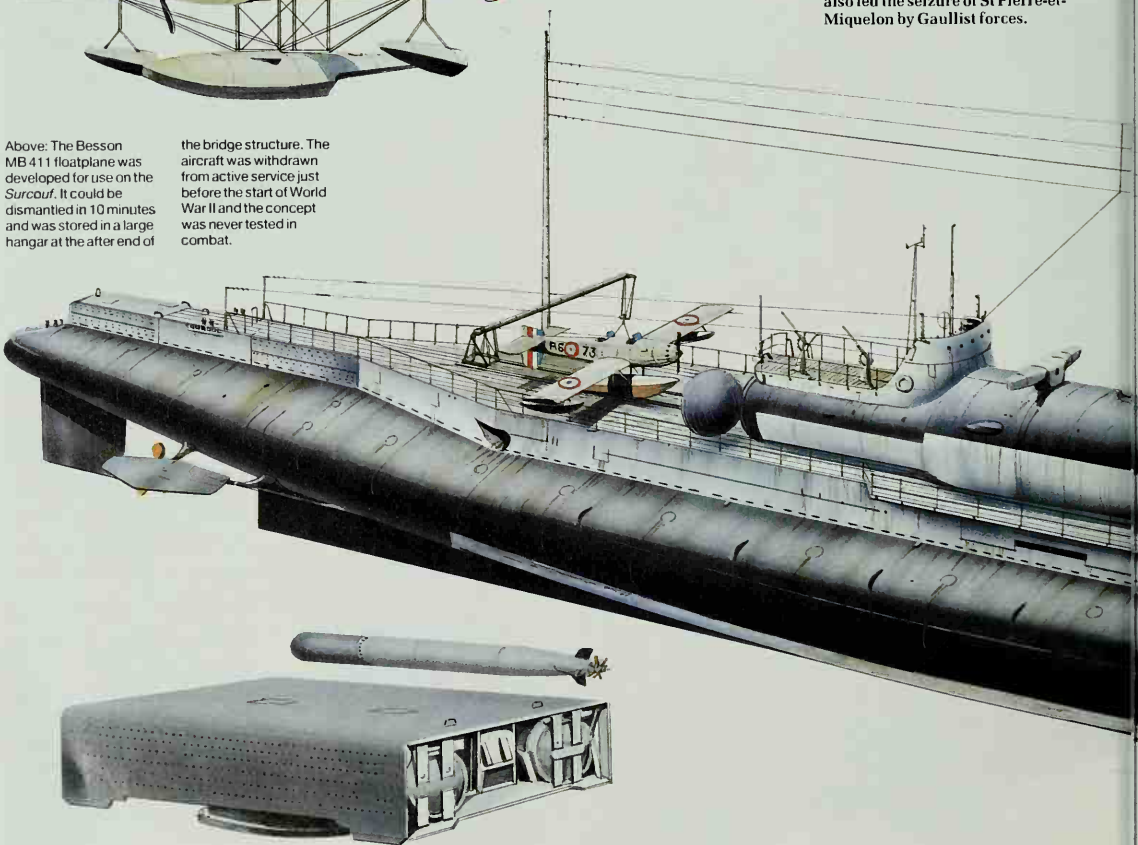
The British built 18 of the K class so-called 'fleet' submarines between 1916 and 1918; they had a submerged displacement of 2,600 tons and were armed with two 4in guns. The next step was the M class which had 12in guns in large turrets forward of the conning tower: of the three built, *M-1* was lost with all hands in 1925, *M-2* was converted into a seaplane carrier and sank when the hangar door was inadvertently left open during a dive, and *M-3* was converted into a minelayer. Another type, the X-1 (3,585 tons submerged), mounted four 5.2in guns in two twin turrets. None of these classes was at all satisfactory and after the X-1 the Royal Navy abandoned this particular line of development.

At this point the French came on the scene with the Surcouf. Designed under the 1926 naval programme, the Surcouf was, in her time, the biggest submarine in the world, her enormous dimensions being necessary to carry all the items considered necessary for her role of world-wide commerce-raiding. The twin 8in turret was forward of the conning tower and was controlled by a director and a 40ft (12m) rangefinder. Abaft the conning tower was an aircraft hangar, with AA guns mounted on its roof. A 16ft (4.9m) motor cutter was also carried to take the boarding party to its prizes, and a compartment was provided for 40 prisoners.

The 8in guns had a range of

Above: *Surcouf* in a Scottish loch during World War II. Designed for an anti-shipping role, she proved difficult to employ as there was so little Axis shipping at sea. She carried out Atlantic patrols and also led the seizure of St Pierre-et-Miquelon by Gaullist forces.

Above: The Besson MB 411 floatplane was developed for use on the *Surcouf*. It could be dismantled in 10 minutes and was stored in a large hangar at the after end of the bridge structure. The aircraft was withdrawn from active service just before the start of World War II and the concept was never tested in combat.



around 15 miles (24,000m), which in theory enabled the Surcouf to deal with armed merchant cruisers and other lightly armed convoy escorts from well outside their guns' maximum range. However, the visual horizon of the director could have been little more than 12,000 yards (11,265m) and it was presumably to extend this range that the seaplane was carried. However, the aircraft – a Besson MB floatplane – was apparently not a success and had been removed by the outbreak of war in 1939, the hangar being used thereafter for stores.

Having taken some seven years to build, Surcouf was commissioned in 1935 and made several lengthy cruises up to the start of World War II. In 1939-40 she served as a convoy escort on several occasions, but was forced to leave Brest on June 18, 1940, to avoid capture by the Germans. She lay at Plymouth, England, for some weeks before being seized by the Royal Navy on July 3; three Britons and one Frenchmen were killed and two men wounded during the incident. Thereafter Surcouf served with a French crew under British operational control. There was much discussion as to the best use for this odd submarine: she was used as convoy escort and for anti-surface raider patrols in the Caribbean, and was also used – under French control – in the operation to bring the islands of St Pierre and Miquelon under Free French control in December 1941. It was then decided to send her to the Pacific where she would be employed in the defence of the Free French Pacific Islands, but she was rammed and sunk with all hands on February 18, 1942, while en route from Bermuda to the Panama Canal. Ironically, having been built to sink merchantmen it was by a US merchant ship, the *Thomas Lykes*, that the Surcouf was sunk.

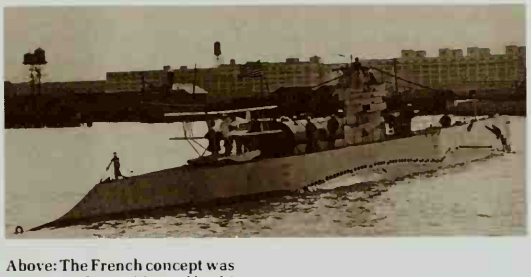
Surcouf was the last attempt to use guns as an alternative to torpedoes for major actions by submarines against surface ships, and apart from being an inherently unlucky boat she spent most of her career in search of a proper role. However, the basic operational concept was not totally unsound and it was the technology that was deficient.

Armament: Surcouf's main armament was two 8in/50 guns, for which 600 rounds were carried. Secondary armament comprised two 37mm guns with 1,000 rounds and two twin Hotchkiss 13.2mm machine guns with 16,000 rounds. No fewer than 12 torpedo tubes were fitted, eight 550mm – four in the bows and four externally aft – with 14 torpedoes and four 400mm tubes internally aft with eight torpedoes.

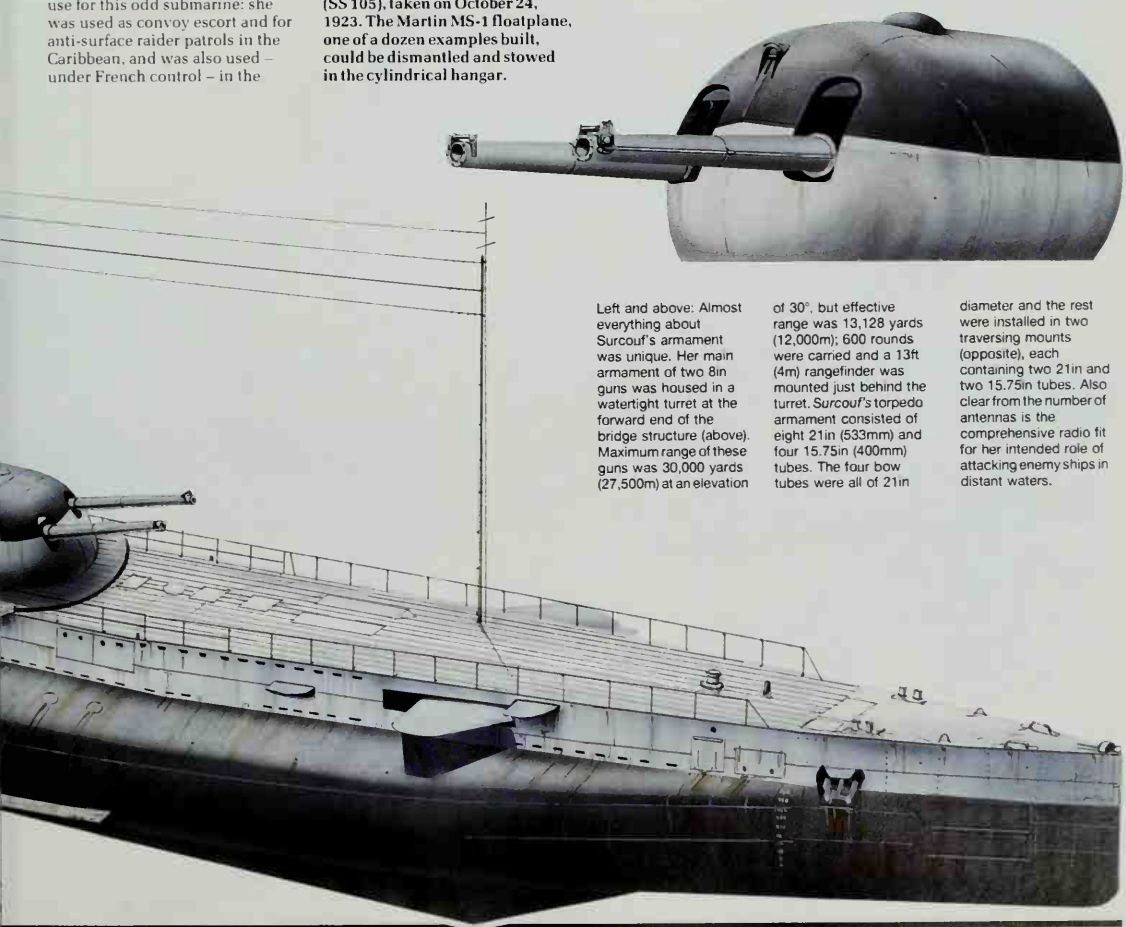
Sensors: Like all submarines of her generation, Surcouf had just two periscopes. A large stereoscopic range-finder with a 13.1ft (4m) base was mounted on the superstructure just forward of the bridge, and she had a good communications fit of HF radios, with two large masts on the port side.

Aircraft: The aircraft, a Besson MB floatplane developed specifically for this application, was withdrawn from use just before the start of World War II. With a span of 32.3ft (9.85m), a length of 22.96ft (7m) and a height of 7.87ft (2.40m) the aircraft was small enough to be placed in a container 13.1ft (4m) square and 22.96ft (9m) long and could be dismantled in 10 minutes. It was powered by a 120hp Salmson air-cooled radial engine.

Construction: Surcouf was launched on October 18, 1929, at Cherbourg.



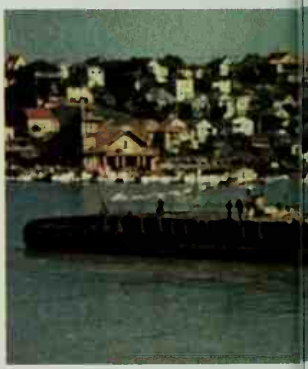
Above: The French concept was not original, as evidenced by this picture of the US submarine *S-1* (SS 105), taken on October 24, 1923. The Martin MS-1 floatplane, one of a dozen examples built, could be dismantled and stowed in the cylindrical hangar.

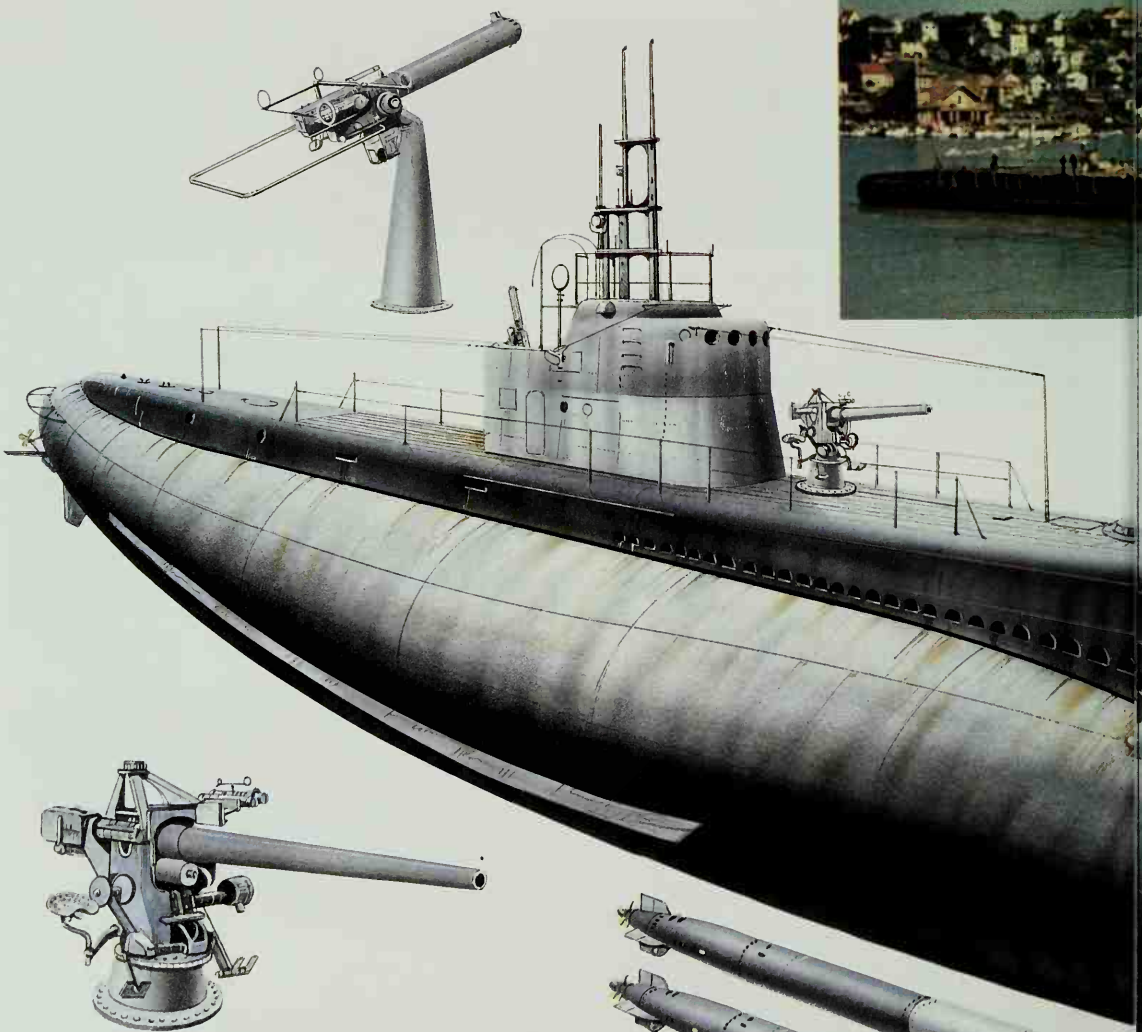


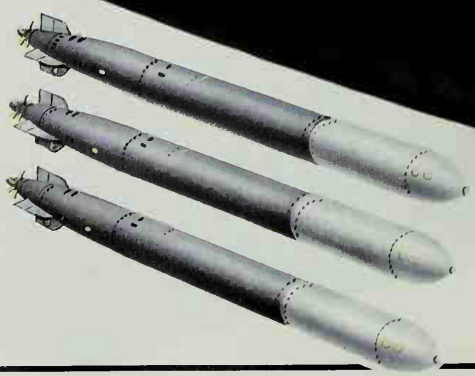
Left and above: Almost everything about Surcouf's armament was unique. Her main armament of two 8in guns was housed in a watertight turret at the forward end of the bridge structure (above). Maximum range of these guns was 30,000 yards (27,500m) at an elevation of 30°, but effective range was 13,128 yards (12,000m); 600 rounds were carried and a 13ft (4m) rangefinder was mounted just behind the turret. Surcouf's torpedo armament consisted of eight 21in (533mm) and four 15.75in (400mm) tubes. The four bow tubes were all of 21in diameter and the rest were installed in two traversing mounts (opposite), each containing two 21in and two 15.75in tubes. Also clear from the number of antennas is the comprehensive radio fit for her intended role of attacking enemy ships in distant waters.

Gato Class

Origin: USA
Type: Patrol submarine, diesel-electric-powered
Displacement: 1,816 tons surfaced; 2,424 tons submerged
Dimensions: Length 311.75ft (95.2m); beam 27.25ft (8.3m); draught 15.25ft (4.7m)
Propulsion: Diesel electric drive on two shafts; four Fairbanks, Morse/General Motors/Hooven, Owens, Rentschler diesel engines; two General Electric/Elliot Motor/Allis-Chalmers electric motors; 2,740shp for 20.25 knots surfaced, 8.75 knots submerged, 10,000-13,000nm at 14 knots, design diving depth 300ft (91m).
Complement: 80-85
Background: Geography dictates that virtually all US Navy warships must operate at considerable distances from the continental USA. Apart from purely coastal vessels, therefore, the majority of its warships, and particularly the submarines, need long range and a good cruising speed to reach their operational areas in a reasonable time. During World War I the enemy was Imperial Germany and Japan was an ally, but the possibility of a confrontation with the ever more powerful Japanese was increasingly important to US Navy planners from the early 1920s onwards. The ranges of operations involved in such a conflict were beyond anything then being considered by other leading navies, and in the major strategic plan – Plan Orange – it was expected that the principal operational base in a war against Japan would be the US west coast, the Philippines and the mid-Pacific islands being presumed lost in the early stages.
Design: The US Navy had long followed a policy of gradual improvement, producing submarines which without excelling in any single aspect of their performance were, nevertheless, extremely reliable, with long range, good habitability







Above: USS *Gato* (SS212) as she appeared in August 1942, at the time of her return from her second operational patrol. Weapon and sensor fits and fin shapes changed constantly throughout the war on all US submarines as experience was gained and new equipment became available. At this stage *Gato*'s principal surface weapon was a 3in/50 gun (above), while a water-cooled 0.50in AA machine gun (top) was mounted abaft the fin. The 21in (533mm) Mk XIV torpedo (right), in use up to 1944, had a range of 4,500yd (4,115m) at 46kt or 9,000yd (8,230m) at 31.5kt. Notoriously unreliable, it was in such short supply that some submarines went out on patrol armed only with mines.

and large numbers of reload torpedoes, all essential attributes in boats operating for protracted periods at great distances from base. Particular emphasis was placed on propulsion, and the US Navy was so determined to have a guaranteed source of really reliable and economical diesel engines that it even assisted in the dieselisation of the US railroads, a policy which resulted in the perfection of four types of high-speed diesel. In addition, it had also experimented in the inter-war years with a composite drive on the S class and direct drive on the Ts and Gs, but for the Gato class it returned to the proven diesel-electric drive.

There had been constant debate in the US Navy about the gun armament for submarines, and so strongly did the naval staff feel about preventing submarine captains from becoming involved in surface actions that they deliberately restricted the armament to one Mk 21 Mod 1 3in/50 anti-aircraft gun. This weapon's inadequacy was proved beyond doubt in the early war years, and US submarines underwent constant up-gunning throughout the war, as did those of most other navies, until the revolution in submarine design led to the elimination of all gun armament. The replacement for the 3in/50 on the Gato class was the Mk 17 5in/25, a 'wet' gun produced from non-corrosive materials, which enabled the muzzle and breech covers to be eliminated. In design terms the Gato class was a progressive development of the Porpoise class, and the Gatos' high surface speed of just over 20 knots proved invaluable in reaching patrol areas and achieving good firing positions for torpedoes.

The all-welded construction facilitated production, which was confined to four yards, the most unusual being that at Maniwotoc on Lake Michigan, some 1,000 miles (1,610km) inland. Not only did the boats have to be launched sideways into the river, but they then had to travel down the Mississippi to reach the sea.

This highly successful class show the soundness of the American policy of developing reliable hull and engine designs over a long period. The US Navy's task was, however, somewhat simplified by having no real requirement for smaller, more manoeuvrable and shorter ranged submarines.

During World War II US submarines, normally operating at considerable distances from their bases, sank over nine-tenths of Japan's major vessels, an achievement in which code-breaking played a considerable part, but to which successful submarine design also contributed. Most of the later fighting was done by the 73-strong Gato class, and by the 132 Balaos and 31 Tenches that were developed from them. Eighteen of the Gato class were sunk by enemy action and one was a constructive total loss.

Above: US Navy prewar policy was one of progressive development, with a series of large boats being produced for operations against Japanese battleships and aircraft carriers. The few US bases were far apart so the boats had long ranges and were more self-sufficient than those of other nations: average range was 10,000nm with stores for 60 days. USS *Swordfish* (SS 193), seen here, belonged to the Salmon/Sargo class, which, with the T class, were the Gatos' immediate predecessors. Swordfish sank the first Japanese merchant ship of the war on December 15, 1942.

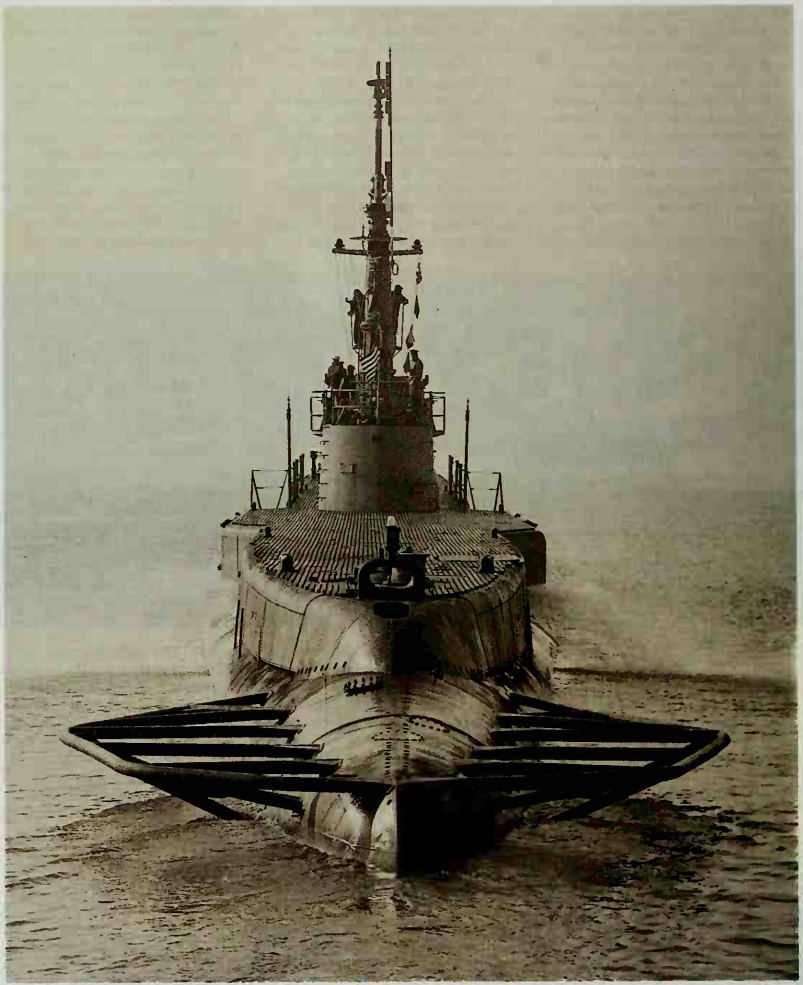
The Gato class is one of those which bridged the gap between the last of the submersibles and the first of the true submarines. In its original form the Gato epitomised the US Navy's long-range attack submarine and operated with great success and distinction against the Japanese, and with the other similar classes, the Gatos played a significant part in bringing Imperial Japan to the verge of surrender by devastating its merchant fleet. However, the Gato class boats were slow under water: their maximum submerged speed was 8.75 knots, and even this could not be sustained for any great period without draining the batteries. Also, as with virtually all their contemporaries, the designed operating depth of 300ft (91m) was a trifle less than the overall length of 311.75ft (95.2m), which imposed considerable constraints on manoeuvrability.

The next class of US submarine – the 132-strong Balao class – was virtually identical with the Gato, but had a strengthened hull, enabling the members of the class to dive to 400ft (122m), and earning them the name 'thick-skinned Gatos'. The Tench class was also based on the Gato, but only 31 had been built when the war ended and production ceased.

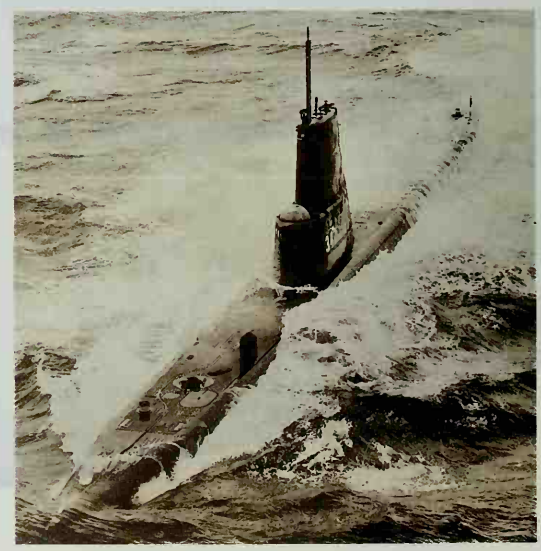
Electronics: The Gato class boats were among the first to have a comprehensive electronics fit, eventually comprising a full range of radar, sonar, communications and electronic warfare equipment. The actual fit was in a constant state of change as new equipment became available and as boats could be spared to have it installed, and masts and antennas proliferated with little effort at reducing drag until by the war's end there was a veritable forest atop every submarine's fin.

The first air search radar small enough to install in a submarine, the SD, became available at the end of 1941, and its small bar antenna was usually mounted at the head of the HF communications rod antenna. The SD gave no directional information, had a maximum range of only 10 miles (16km) and was easily detected by enemy RDF; nevertheless, it met the submariners' urgent need for early warning of the approach of an aircraft, and by mid-1942 all US submarines were fitted with SD, while the SJ, which gave both range and bearing, was starting to enter service. Although difficult to calibrate and somewhat unreliable, the SJ gave submariners a totally new capability, and when the circular plan position indicator display replaced the earlier horizontal line display great confidence was placed in the system. The SJ antenna was ovoid, originally solid but later a lattice, and unlike the SD it had a mast of its own. The last wartime set was the SS.

Sonars, too, were being constantly improved, and by 1945 most US submarines had the active



Above: USS *Perch* (SS 313) of the Balao class. The Balaos were virtually identical to the Gatos, but design changes to facilitate rapid building resulted in greater structural strength and an increase in diving depth from 300ft (91m) to 400ft (122m). This photograph shows clearly the many protrusions on a typical World War II submarine. As well as creating considerable underwater drag, leading to low speed and limited endurance, they were a source of considerable noise, making them readily detectable.



Right: USS *Cubera* (SS 347), a postwar GUPPY-2 (Greater Underwater Propulsive Power) conversion of a World War II Balao class boat. Comparison with the original configuration (above) shows the streamlining and the way external fittings have been either removed or made retractable. These measures, allied to more powerful batteries, led to great increases in underwater performance.

Above: As the GUPPY conversion was relatively expensive ($2.5 million each at 1950 prices) 19 boats were given a simpler 'Fleet Snorkel' modernisation, involving the removal of deck armament and streamlining the fin. This is USS *Sabalo* (SS 302) in the mid-1960s; she was stricken in 1971.

WFA system, which combined echo-ranging, listening and sounding using a retractable keel-mounted dome. The latter feature prevented the sonar from being used when the submarine was lying on the bottom, and a passive listening device was therefore mounted topside. Initially the JP, a converted surface patrol craft set, was used; like the later JT it enabled the submarine to detect surface ship propeller noise at ranges of up to 20,000 yards (18,288m) and was also used to detect self-noise. The JP was manually rotated but the later JT was powered and consisted of a 5ft (1.53m) line hydrophone with a 22° beam scanning at 4rpm. It covered the sonic (100Hz-12kHz) and, with a converter, supersonic (up to 65kHz) frequencies. A new and highly specialised type of sonar came into use late in the war: the FM, later redesignated QLA-1, was a precision mine-evasion sonar which was so effective that US submarines were able to work in Japanese home waters with relative confidence.

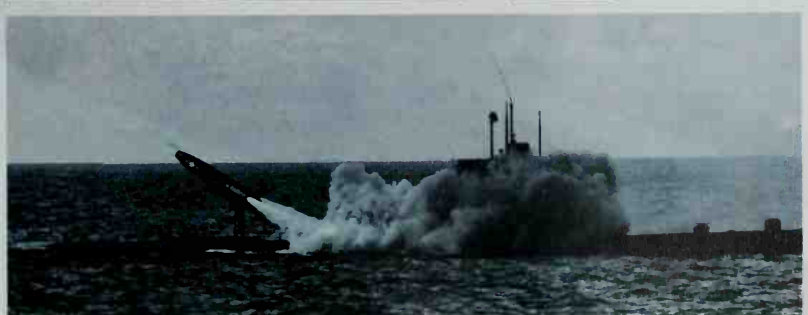
Other sensors included the usual two periscopes, Number 1 for search and Number 2 for attack, and there was a variety of radio masts, whip antennas and stubs, the actual fit changing with bewildering rapidity. Electronic warfare equipment also began to be fitted, one external indication being a large direction-finding loop. Finally, for surface actions with the gun, there were two target bearing transmitters mounted on the bridge.

Armament: As built, the Gatos were armed with one 3in/50 gun in line with the prewar policy of ensuring that a submarine captain would not be given a gun which might encourage him to fight it out on the surface. However, weapons were progressively added throughout the war and by 1945 armament normally comprised one 5in/25 gun and two 40mm and two twin 20mm cannon. By 1950, however, the Guppy conversion programme (described below) had eliminated the guns.

There were ten 21in torpedo tubes, six forward and four aft, with 24 reloads, and while the boats themselves were very reliable the torpedoes were far less so. Certainly, the Mk 14 torpedo with its Mk VI magnetic exploder used from 1941 to 1943 was notoriously unreliable; the torpedo ran much deeper than designed and left a prominent wake, while the exploder frequently failed to detonate and the back-up contact exploder only seemed to work when hitting the target a glancing blow. Later in the war the Mk 18 torpedo, a direct copy of a captured German G7e, was widely used, and was credited with sinking a million tons of Japanese shipping.

Construction: The 73 boats of the Gato class were launched between 1941 and 1943, construction being shared between Electric Boat, Groton (41), Portsmouth Navy Yard (14), Mare Island Navy Yard (4) and Maniwotoc, Wisconsin (14). Of the 54 that survived the war, most were converted to Guppy 1 (Greater Underwater Propulsive Power) standard: all guns and other external protuberances were removed, the sail was streamlined, a schnorkel was fitted and new, lighter and much more powerful batteries were fitted. This conversion, based on the lessons of the German Type XXI, had a dramatic effect on performance, with considerable increases in underwater speed and range. Of the remaining boats six were transferred abroad and seven converted to hunter-killer submarines with more powerful batteries for a higher underwater speed. Another six were converted to radar pickets in 1951-52, with an extra 31ft (8.3m) portion added to their hulls. *Tunny* (SS-282) was converted into a Regulus I missile launching submarine and was then again altered to a troop-carrying submarine in 1964.

Left: The first US strategic deterrent submarines carried Regulus, a cruise missile only launched from the surface. Final preparations for launch took place on deck outside the hangar; a further hazard was that if the hangar accidentally flooded the boat would turn turtle. USS *Tunny* (SSG 282), built in 1941 as a Gato class fleet boat, was one of the first operational conversions.



Left: USS *Tunny* (SSG 282) launches a Regulus I missile in the 1950s; two missiles were carried in the portly hangar. Regulus I was a turbojet-powered remote-controlled aircraft, which flew at a speed of about Mach 0.9 and had a range of some 400nm. It cruised at a height of over 30,000ft (9,144m) until near its target, guided by radio signals from submarines at periscope depth whose position was known from Loran. Its warhead was a 120kT W-5 nuclear device, and the system was designed to be used only against large fixed targets.

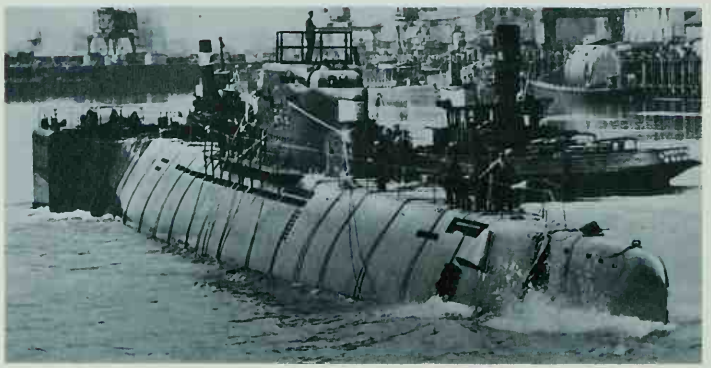
Type XXI

Origin: Germany, first unit completed 1944
Type: Patrol submarine, diesel-electric powered
Displacement: 1,621 tons surfaced; 1,819 tons submerged
Dimensions: Length 251.6ft (76.7m); beam 21.7ft (6.6m); draught 20.7ft (6.3m)
Propulsion: Diesel-electric drive on two shafts; two MAN M6V 40/46 diesel engines, each 1,000bhp at 522rpm; two SSW or AEG GU 365/30 electric motors for normal running, each 2,500hp; two SSW GW323/38 electric motors for silent running, each 83kW; 15.6kt surfaced, 17.2kt submerged (5kt in silent mode), 11,150nm at 12kt surfaced, 285nm at 6kt submerged; design diving depth 435ft (133m)
Complement: 57
Background: By the middle of 1943 German submarine losses were reaching unacceptable levels as a result of Allied improvements in anti-submarine equipment and techniques, and it appeared to Admiral Dönitz that sonar and radar, together with the ever more effective use of ships and aircraft, were proving too much for his captains. To a large extent he was correct, although he was not to know that electronic warfare, and in particular the breaking of the Enigma code, was having a major influence in enabling Allied ships and aircraft to be in the right place at the right time. What was required, in the German view, was a true submersible, which would be able to operate for protracted periods under water and to avoid detection by radar or sonar. It would also improve survivability if the boats could operate at considerably higher speeds and so would be able to outrun surface hunters.

Professor Walther had been experimenting for some years with both streamlining and propulsion. His hydrogen peroxide powerplants proved too unreliable for operational use, although a number of boats with such units were built, and the only alternative at the time was to streamline the outer casing and to vastly increase the battery power of diesel-electric boats. Accordingly, new hull forms were adopted which made possible higher speeds under water than those achieved on the surface, while the adoption of the snorkel, which had been invented by a Dutch naval officer in the late 1930s, enabled the resulting Type XXI to travel at periscope depth using its diesels rather than its batteries.

The new boat's performance was remarkable: periscope depth could be reached in 10 seconds and 100ft (30.5m) in 40 seconds – much faster than anything else then in service – but the numerous flooding and ventilation openings involved added considerably to drag and the number of apertures was reduced, adding some 15

Right: The after anti-aircraft turret, mounting two 20mm cannon. Despite the intention to make the Type XXI a true submarine and the deletion of the deck gun, the designers still kept anti-aircraft cannon, presumably as a result of the experiences of the older U-boats. In fact, of the nine Type XXIs actually sunk on patrol, three were mined and the remaining six were lost during attack from aircraft.



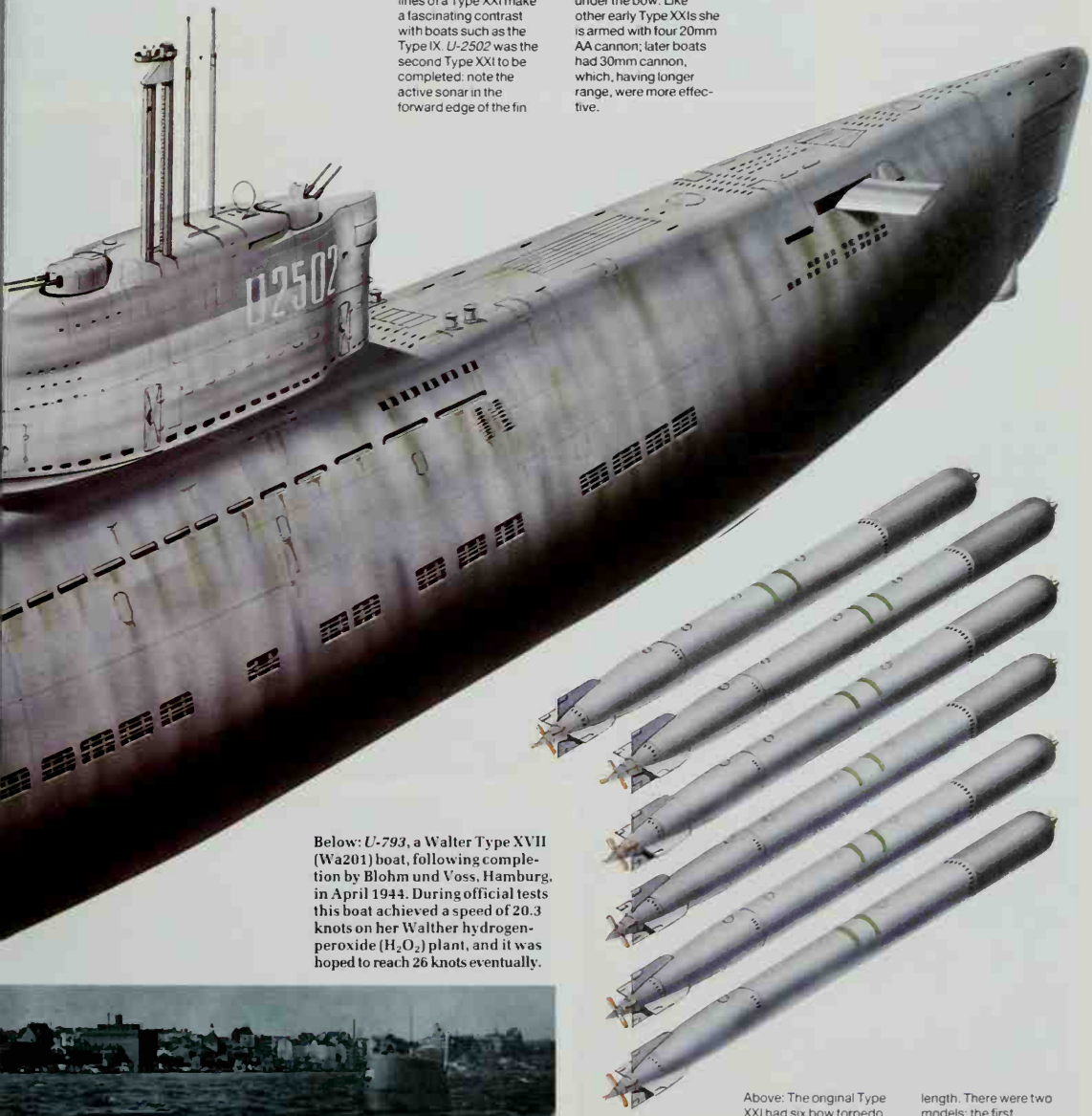
Above: A Type XXI immediately after launching at the AG Weser yard at Bremen, probably in 1944. The guard rails were only fitted for the launch and fitting-out, and were then removed. Note the anti-aircraft cannon in the streamlined mounting at the forward end of the sail; there is another twin mount at the after end.

seconds to the diving time.

Safe operating depth was 435ft (132.6m), but with a safety factor of 2.5 it could operate down to approximately 700ft (213m), beyond the Allied sonar's effective range of approximately 400ft (122m). Underwater speed and endurance put it in a totally new class: the maximum underwater speed of 16.7 knots could be sustained for 72 minutes, while 12 knots could be kept up for 5 hours and endurance at its 'silent' speed of 5.2 knots was around 72 hours, compared with the Type VIIC's endurance of just 45 minutes at five or six knots. The snorkel enabled the Type XXI to cruise almost indefinitely below the surface and was virtually undetectable by the contemporary airborne radars, especially in anything over Sea State 2. The streamlining of hull and fin also led to a significantly smaller sonar cross-section, and the effect was reinforced by the use in some cases of anti-radar and anti-sonar coatings.

The Type XXIs were designed for easy fabrication and no fewer than 131 were completed. However, the chaotic state of Germany in the final stages of the war and Dönitz' decision to order the type straight into production without any prototypes meant that very few attained operational status. Those that did overcome their teething troubles and actually carry out operational patrols found that the revolutionary design did indeed confer undreamt-of improvements, and a number of successes were achieved. Fortunately for the Allies, however, the boats were too late to

Below: The exceptional lines of a Type XXI make a fascinating contrast with boats such as the Type IX. *U-2502* was the second Type XXI to be completed: note the active sonar in the forward edge of the fin and the passive array under the bow. Like other early Type XXIs she is armed with four 20mm AA cannon; later boats had 30mm cannon, which, having longer range, were more effective.



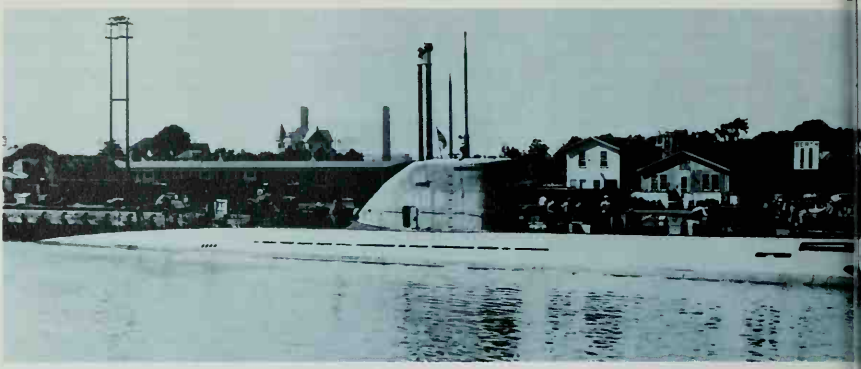
Below: *U-793*, a Walter Type XVII (Wa201) boat, following completion by Blohm und Voss, Hamburg, in April 1944. During official tests this boat achieved a speed of 20.3 knots on her Walther hydrogen-peroxide (H_2O_2) plant, and it was hoped to reach 26 knots eventually.

Above: The original Type XXI had six bow torpedo tubes, although it was planned to fit additional sets of side tubes in later models. The G7e torpedoes shown here were 21in (533mm) in diameter and 23.5ft (7.163m) in length. There were two models; the first (codename Geier) had acoustic homing, while the second (codename Lerche) was wire-guided, using acoustic information passed back along the wires.

make a major impact; 120 were sunk or scuttled and 11 surrendered.

The US, British, French and Soviet navies all used their captured Type XXIs for experimental and development purposes in the early postwar period. The US Navy developed a new class, based on many of the features of the Type XXI; the Tang (SS-564) class, of which only six were built, improved on the performance of the Type XXI, most notably in operating depth, safe depth being 700ft (213.4m) and collapse depth 1,100ft (335.3m). With the prospect of nuclear submarines on the horizon, however, the US Navy did not want to produce a large class of new diesel-electric boats, instead converting many of its excellent and relatively new Gato, Balao and Tench class submarines to the new Guppy standard.

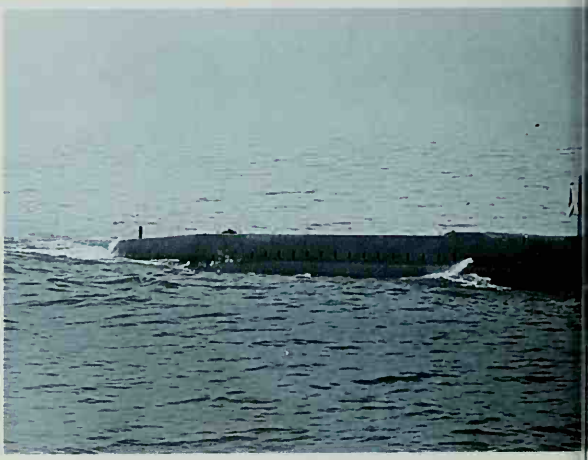
The Soviets made the staff at the Schichau yard in Danzig (Gdansk) finish the five Type XXIs which had been laid down as *U-3538* to *U-3542* and then produced a further unknown number in the USSR; they were followed by the Whiskey class, which was produced in vast numbers. The British carried out a number of experiments on the Walther hydrogen-peroxide system in the

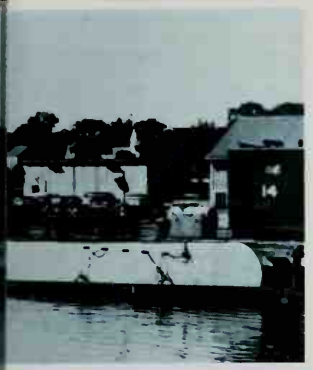


Above right: *U-3008* at the US Portsmouth Navy Yard, August 30, 1946, with periscopes and radar masts raised. Several Type XXIs were examined and tested with great interest by the Allies, who had nothing comparable.

Right: Following tests of the captured German Type XXIs the Americans built the Tang class in the early 1950s. This is USS *Gudgeon* (SS 567), still serving the Turkish Navy as *Hizir Reis*.

Below: Name-ship of her class, USS *Tang* (SS 563), off Hawaii in 1964, her descent from the Type XXI clear from her lines. Like *Gudgeon* she serves on with the Turkish Navy as *Piri Reis*.





late 1940s and 1950s, and even built two boats using this system, HMS *Explorer* and *Excalibur*, but concluded – to the great relief of their crews – that this was not the way ahead. Instead, the Royal Navy, like the US Navy, modernised a number of its World War II boats, but then built the very successful Porpoise and Oberon classes, whose design was based on the lessons of the Type XXI but which, like the Tangs, did not use the German figure-8; they also achieved significantly better diving depths.

The French used the Type XXI as the basis for their Narval class, of which six were built in the years 1951-54. The West German Bundesmarine also recovered a Type XXI which had been scuttled in 1945, and used it for many years as an experimental submarine under the new name *Wilhelm Bauer*.

The Type XXI thus had its main impact in the first decade of the postwar era, when it formed the basis of all diesel-electric submarine development. The next stage, which took submarine evolution a further great leap forward, was the US Navy's *Albacore*.

Armament: The Type XXI was the first World War II submarine type to reverse the trend of increasing surface armament, weaponry being confined to four 20mm or 30mm AA cannon in twin streamlined turrets at either end of the fin. There were six 21in (533.1mm) bow-mounted tubes with 23 torpedoes carried. Part of the torpedo load could be replaced by mines.

Sensors: Too many U-boats had been attacked on the surface by aircraft, due to Allied advances in aircraft radars. The Germans, therefore, developed a series of radar detectors designated Funkmess Beobachtunggerat (FuMB), with individual models being named after islands. The Type XXI normally carried an FuMB-29 Bali I detector, with the antenna mounted on top of the schnorkel mast, although later this was replaced by the FuMB-37 Leros in many boats. A DF loop was also installed at the forward end of the fin.

U-boats were fitted with active air- and surface-search radars during the course of the war, like their Allied counterparts, the sets being designated Funkmess-Ortungsgerat (FuMO), and Type XXI boats used the FuMO-61 Hohentwiel-Drauf model, with a rectangular antenna array on a short mast.

Radio antennas included a UHF antenna mounted beside the bridge and an HF rod antenna on its own extending mast. Surprisingly, despite the requirement for silent operation, two long-wire HF radio antennas were mounted fore and aft; such devices always have a tendency to vibrate at speed.

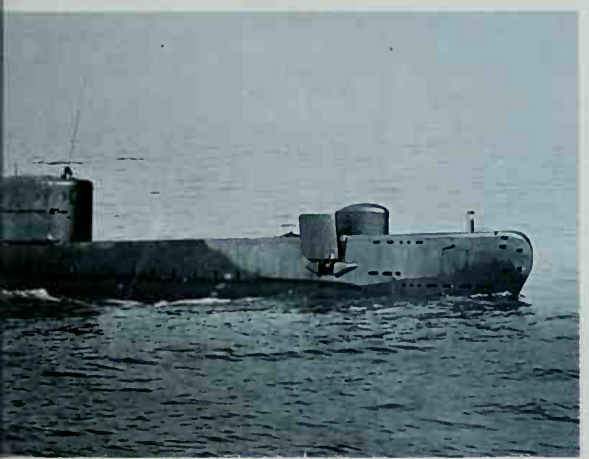
The usual very effective German sonars were used. A Schallortung-Gerät, or active sonar set, located in the forward edge of the fin structure provided bearings of ± 100° with a directional accuracy of ±0.5°.

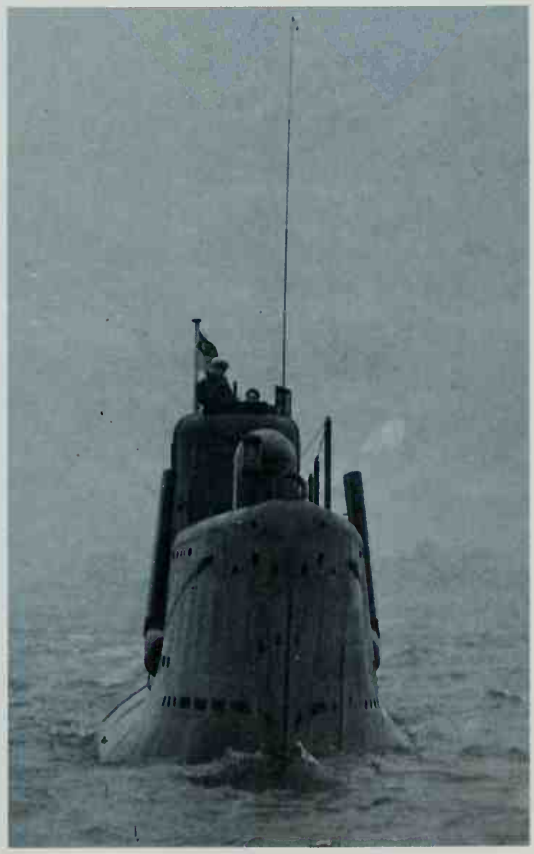
A Balkon (balcony, or gondola) array was built in under the bow to provide passive detection out to ranges at least as good as those being obtained by Allied sonars, though its location prevented this device from covering the angled segment aft of 150°-210° and it was, therefore, intended to install a Schallortung-Passiv Anlage (passive listening device) on later Type XXIs; SPA consisted of a swivelling bar with two passive receiver elements mounted under a streamlined, hooded fairing on the after casing.

Construction: One hundred and thirty-one Type XXI boats were completed between 1944 and the end of the war. The yards involved were Blohm und Voss, Hamburg, Weser, Bremen, and Schichau, Danzig (Gdansk). The last yard also completed at least five more boats at the behest of the Soviets.

Right: HMS *Excalibur* had Type 187 sonar dome and short sail, a submerged displacement of 1,000 tons and a length of 225ft (68.6m) she had a diving depth of 550ft (167m). She and her sister were developed from the Type XVII, one scuttled example of which *U-1407* – was raised and recommissioned as HMS *Meteorite*.

Below: HMS *Explorer* at sea in 1956. The Royal Navy saw the Walther propulsion process as a cheaper alternative to nuclear power, but controlling the hydrogen peroxide proved too difficult, despite the presence of Helmut Walther and five colleagues at the Vickers yard at Barrow from 1946 to 1949.





Albacore

Origin: USA, completed 1953
Type: Experimental submarine, diesel-electric powered (AGSS)
Displacement: 1,500 tons surfaced; 1,850 tons submerged
Dimensions: Length as built 203.75ft (62.1m), length after Phase III modification 210.5ft (64.2m); beam 27.5ft (8.4m); draught 18.5ft (5.64m)
Propulsion: Diesel-electric drive on one shaft; two General Motors radial diesels; one Westinghouse electric motor; 15,000shp for 25kt surfaced, 33kt for short periods submerged
Complement: 52
Background: From World War I onward the submarine hull form was essentially long and narrow: even the Type XXI and the still later USS *Nautilus*, the first nuclear-powered attack submarine, were of this shape. It had been discovered, however, that the Type XXIs and their derivatives tended to pitch at high underwater speeds to the point where, under certain conditions, control could be lost. The US Navy in a postwar programme developed a new hull form based on that of an airship and an experimental diesel-electric submarine, USS *Albacore*, was built to test this new shape. Initially conceived as a high-speed underwater target for surface ASW forces and financed by the cancellation of a destroyer conversion programme, *Albacore* was to prove one of the great milestones in submarine development.
Design: *Albacore*'s hull form was a body-of-revolution, that is to say, like a torpedo, symmetrical around its long axis. The results showed that the new shorter, fatter hull was very much more manoeuvrable, being capable of turning at 3.2°/sec compared to 2.5°/sec or less for the more traditional hull. Indeed, the *Albacore* proved that a submarine could be 'flown' in three dimensions like an aircraft, making tight banked turns and even, it is rumoured, looping. The new hull was also dynamically stable at all speeds and could be driven faster for a given power; the boat needed only 136hp to sustain seven knots, and with her full 15,000shp could travel for brief periods at over 33 knots, a hitherto undreamt-of underwater speed. Moreover, the single propeller was not only much more efficient, but also much quieter, so helping to avoid detection by hostile anti-submarine forces. There were internal benefits, too, since the fatter hull could accommodate a multi-deck layout, providing greater storage space and better habitability.

The *Albacore* was used to test a variety of features. In her original state she could travel at 26 knots submerged, but with silver-zinc batteries and contra-rotating propellers – both fitted later in Phase IV of the programme – she

Above: This 1960 photograph of USS *Blueback* (SS 581), one of the three members of the last conventionally powered submarine class to be built for the US Navy, shows her teardrop-shaped hull. These Barbels were built with bow-mounted hydroplanes as shown, but these were eventually moved back to the fin.

could achieve an amazing 33 knots. Another feature was an aircraft-type dive brake abaft the fin to control inadvertent dives. Although German World War II research had shown that at underwater speeds above 12 knots bow planes tended to destabilise the submarine in a vertical plane, the *Albacore* was built with bow hydroplanes; these were apparently very successful, but were not adopted for subsequent production classes, which all had fin-mounted planes. She originally had cross-shaped after control surfaces but was later modified (Phase III) to test an X-configured stern empennage. Although this has certain advantages, and has since found favour with the navies of Sweden and the Netherlands, it has not been pursued further by the US Navy.

As a result of the dramatic demonstrations by the *Albacore* the hull forms of the next class of US Navy nuclear powered attack submarine, the Skipjack class, and the last class of US diesel-electric submarines, the Barbel class, were altered, with great benefits to their performance. The details were also made available to the United States' allies, as a result of which a number of designs, among them the Japanese Uzushio and Yuushio and the Dutch Walrus and Zwaardvis classes, make use of what became known as the 'Albacore hull'.

Armament: Albacore carried no weapons.

Electronics: As an experimental submarine *Albacore* was used to test various sonar and other sensor fits. One such was a bow-mounted BQR-2 with digital multi-beam steering (DIMUS), which enabled a submarine to listen in all directions and to detect weak signals which might otherwise be lost in the background noise. It was estimated that DIMUS, as applied to the BQR-2, increased detection range by a quiet submarine against a schnorkelling submarine from 50 to 70nm (93 to 130km). DIMUS also considerably enhanced multi-target tracking capability.

Construction: One unit only was constructed at Portsmouth Naval Yard. Laid down on March 15, 1952, launched on August 8, 1953, and commissioned on December 5, 1953, she was withdrawn from active service in 1972 and stricken on May 1, 1980.

Left: USS *Albacore* (AGSS 569), one of the truly great milestones in submarine history. Her hull was designed as a body of revolution – that is, symmetrical about the horizontal axis – and based on airship practice. This shape gave dynamic stability at all speeds, resulted in truly outstanding manoeuvrability, and permitted a substantial increase in internal volume, which in turn enhanced crew comfort. *Albacore* tested various devices; completed in the configuration shown here, with a cruciform tail empennage, she later tasked X-shaped control surfaces, a feature not adopted by the US Navy but currently used by some others.

Right: USS *Barbel* (SS 580) showing her 'Albacore' hull to good effect, although it can be seen that various compromises have been made with the perfect symmetry of the true body of revolution. There is, for example, a flat-decked casing to enable the crew to move along the upper works, while the continuous curves of the experimental *Albacore* have been replaced in a production design by a cylindrical centre body, almost as efficient and a great deal less difficult to construct.

Nautilus

Origin: USA, launched 1954
Type: Attack submarine, nuclear-powered
Displacement: 3,764 tons surfaced; 4,040 tons submerged
Dimensions: Length 319.4ft (97.4m); beam 27.6ft (8.4m); draught 22ft (6.7m)
Propulsion: One S2W Westinghouse pressurized water-cooled reactor on two shafts; 15,000shp for 20+kt surfaced, 22.5kt submerged
Complement: 105
Background: The one insurmountable problem with diesel-electric submarines is that they must periodically approach the surface to run their diesel engines and recharge their batteries and to replenish life support systems, and even when just the head of a snorkel is exposed there is a great danger of detection. Following the experiences of both sides in World War II a major search started in the mid-1940s to find an answer to this problem: by chance the technological answer was at hand, having been developed for an entirely different purpose. It had been appreciated from early on in the US nuclear weapons programme that a controlled nuclear reaction could produce enough heat to generate the steam to power conventional steam turbines. Such a concept offered particular advantages for submarine propulsion in that the reaction required no oxygen whatsoever and would give great range between core renewals. Accordingly, in 1949 the US Chief of Naval Operations issued a formal requirement for a nuclear-powered submarine with an in-service date of January 1955.
Design: Research and development into a submarine reactor had started in the USA at the Argonne National Laboratory as early as 1948 and was subsequently transferred to Westinghouse at the Bettis Atomic Power Laboratory. The Submarine Thermal Reactor Mark II which resulted from this work was later redesignated the S2W and was installed in the new hull of the *Nautilus*. The S2W initially had a core enriched by only some 18-20 per cent, but her second and subsequent cores were enriched by over 40 per cent, giving a much higher energy density. This improvement is reflected in the core lives: the first core drove Nautilus 62,562nm (100,681km), the second 91,324nm (146,968km) and the third 150,000nm (240,000km).

A key factor in this programme was the appointment of one of the outstanding submarine officers in history, Captain (later Admiral) Hyman G. Rickover, USN. USS *Nautilus* (SSN-571) was commissioned on September 30, 1954, and on January 17, 1955, she was able to make the historic signal, 'Under way on nuclear power', thus giving the US Navy a lead of three or four years over its Soviet counterpart. *Nautilus* was by far the largest submarine to have been built at that time and designed with a conventional hull based on Type XXI and Guppy

Above: Like the contemporary Nautilus, *Sea Wolf* (SSN 575) had a traditional, pre-Albacore hull. *Sea Wolf*'s liquid sodium reactor proved very troublesome and was replaced after two years.

Above: USS *Nautilus* (SSN 571) achieved man's dream of true and protracted underwater operations. But while the propulsion system was revolutionary, her hull form was the traditional long, thin design with twin propellers. Her submerged speed was 22.5kt and it was only when nuclear power was married to the Albacore hull in the Skipjack class that the full potential of these new developments was realised.

technology rather than an Albacore hull, presumably to avoid risking too many revolutionary advances in one project. (Indeed, it was some time before the US Navy adopted the new hull form, and the next five SSNs – *Sea Wolf*, and the four-boat Skate class – all had the old type of hull.) *Nautilus* had two shafts, driving two small, outward-rotating high-speed propellers on which she could achieve a sustained 22.5 knots submerged, considerably better than any other submarine then in service. A diesel engine was fitted as a stand-by, together with a snorkel and emergency batteries. She was armed with six bow-mounted 21in torpedo tubes, but unlike most of her contemporaries in the early 1950s did not have any stern tubes.

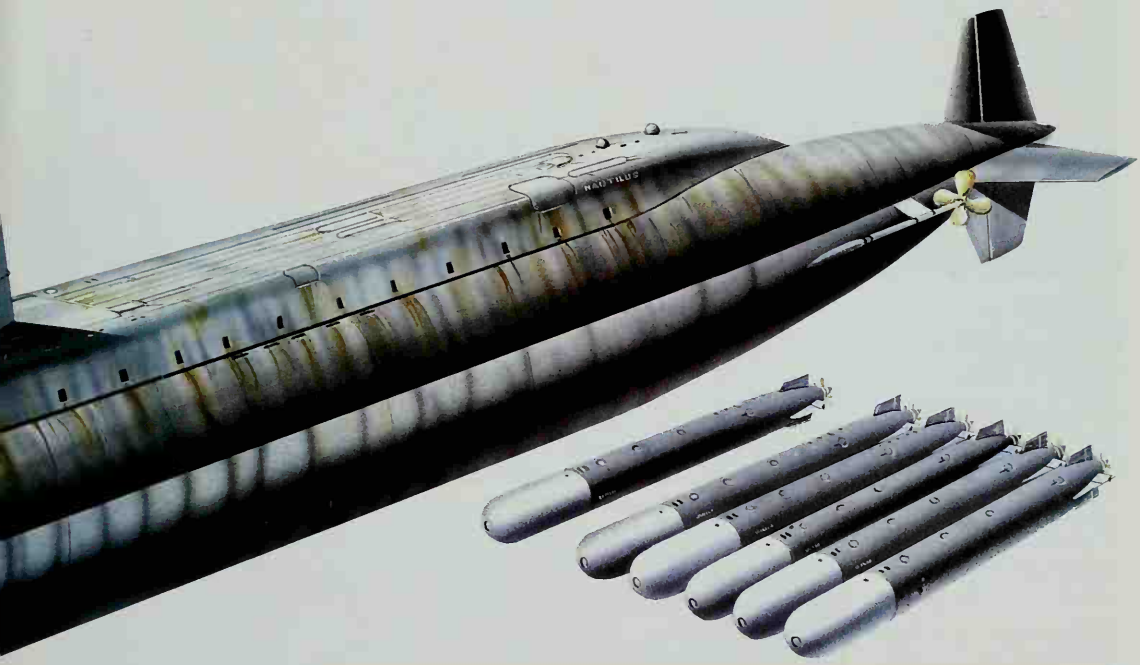
A similar hull was used for the second nuclear-powered submarine, USS *Sea Wolf* (SSN-575), used to test the S2G liquid sodium-cooled reactor which was thought to offer potential advantages over the pressurized water-cooled system. Known as the Submarine Intermediate Reactor (SIR) and developed by Westinghouse at the Knolls Atomic Power Laboratory, the S2W finally powered *Sea Wolf* on January 21, 1957, just over two years after *Nautilus*' success. Liquid sodium cooling had looked attractive as it offered much greater operating temperatures, giving more efficient heat transfer, but it had numerous drawbacks, including the fact that the working fluid had to be kept liquid at all times or it would freeze in the pipes and ruin them. Altogether, the S2G gave a great deal of trouble, including a superheater leak, and in December 1958 it was replaced by a pressurized water-cooled S2Wa reactor similar to that installed in *Nautilus*. Reports of liquid-metal cooled reactors have appeared from time to time since the *Sea Wolf*, notably as power plants for the Soviet Alfa class and the French *Rubis*, but none has been confirmed.

During her service the *Nautilus* made numerous historic voyages. By 1958 the US Navy had sufficient confidence in her capabilities to send her on the first submarine polar transit, starting in Hawaii and finishing in Portland, England, after passing under the North Pole on August 3, 1958. Her first refuelling took place in 1957, the second in 1959 and the third in 1964.

Armament: *Nautilus* was armed with six 21in bow-mounted torpedo tubes.

Electronics: *Nautilus* was equipped with conventional 1950s electronics and communications equipment. Primary sonar was the BQS-4 and the BQR-2C, the former comprising seven vertically-stacked transducers inside a BQR-2C and operated in listening, single-ping and automatic echo-ranging modes with a typical range of 600-8,000 yards (549-7,315m). The BQR-2C was a passive sonar with 48 3ft (0.9m) vertical elements in a 6ft (1.82m) circular array. Performance was claimed to be excellent, with auto target following on a noisy submarine with an accuracy of 0.25° at 12,000 yards (10,973m).

Construction: Constructed at the Electric Boat Company yard at Groton, Connecticut, *Nautilus* was laid down on June 14, 1952, launched on January 21, 1954, and commissioned on September 30, 1954. She was subsequently used as a research craft, before being decommissioned in the early 1980s. She is now on display at a museum.



Right: A significant advance achieved by the nuclear boats was their ability to travel under the Polar ice-cap. The first such trip was made by *Nautilus* in August 1958; here USS *Skate* (SSN 578), name-ship of the production class that followed *Nautilus*, surfaces through the Arctic ice in 1961.

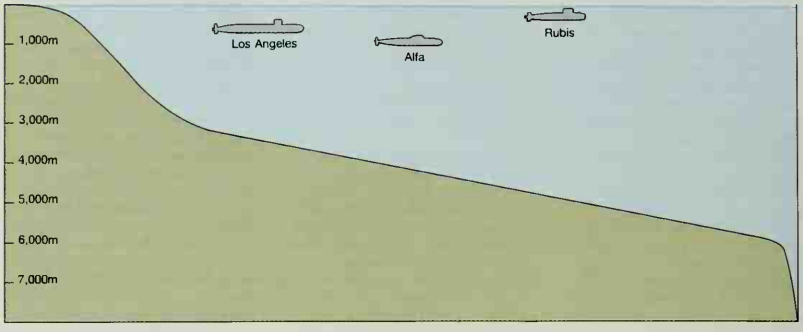
The Oceans

It seems to be generally assumed that submarines, almost since their inception, have roamed at will in an underwater world of which they are the masters, moving in the depths of the oceans among the hills and canyons of the ocean bed. Nothing could be further from the truth: even today the most modern submarines penetrate only marginally into the ocean's depth, and during World War I they barely even left the surface. The submarines of 1915 had operating depths of around 180ft (55m), those of 1945 could reach 400ft (122m) or so, and even today's Los Angeles class can scarcely exceed 1,500ft (450m), although the Soviet Alfa class is reputed to have an operating depth of around 2,500ft (700m).

Even the Alfa's performance seems poor when it is considered that the abyssal plains, which form the floor of most of the underwater world, lie at an average depth of some 12,000ft (3,700m), and the deepest trenches extend down beyond 30,000ft (9,100m). The most sophisticated and specialised underwater vehicles are required to penetrate to such depths: for example, the US research submersible *Alvin* can operate down to 13,500ft (4,000m) and the bathyscaphe *Trieste* reached 35,600ft (4,500m) in the Challenger Deep in the Marianas Trench, where the pressure exceeds one ton per square inch.

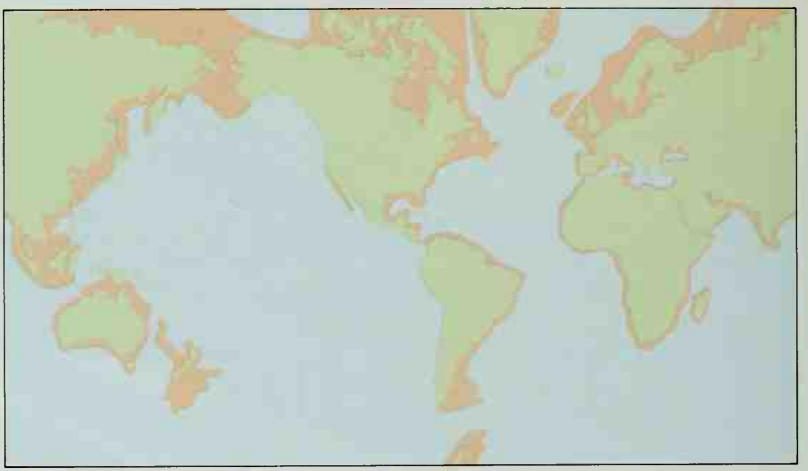
Combat submarines have no current need to operate at such depths, but even so the world in which they must live and fight is quite different from that experienced on land. Over 70 per cent of the earth's surface is covered by oceans, a vast and still relatively unexplored part of the world whose topography, geology and specific nature are only imperfectly understood. Indeed, in many ways we know more about the Moon and the nearer planets than we do about our own oceans, which have been described as the last frontier but one, with only outer space being a greater challenge. It is essential to have some understanding of this different environment in order to appreciate both how submarines survive and operate, and also how the primary means of detecting submarines – sound – is affected.

Ocean depth profile and typical submarine operating depths



Above: Typical diving depths of current submarines compared with the average ocean depth distribution. Submarines do not dive as deep as is popularly assumed. Los Angeles SSNs operate at 1,500ft (450m) and titanium-hulled Soviet Alfas at 2,500ft (700m), but the French Rubis class are limited to 300m (980ft).

Continental shelves



Below: Continental shelves (orange) extend from the coastlines reaching a depth of about 400ft (130m) before the continental break and a rapid increase in depth.

THE OCEANS	
Total surface area	139,400,000sq miles/361,000,000km^2
Overall average depth	12,450ft/3,795m
Pacific average depth	13,215ft/4,082m
Atlantic average depth	10,932ft/3,332m
Indian average depth	12,785ft/3,897m
Mean temperature	39.02°F/3.90°C
Mean density	64lb/cu ft/1.03gm/cm^3
Earth surface area	197,000,000sq miles/510,000,000km^2
Land surface area	57,500,000sq miles/149,000,000km^2

OCEANIC TOPOGRAPHY

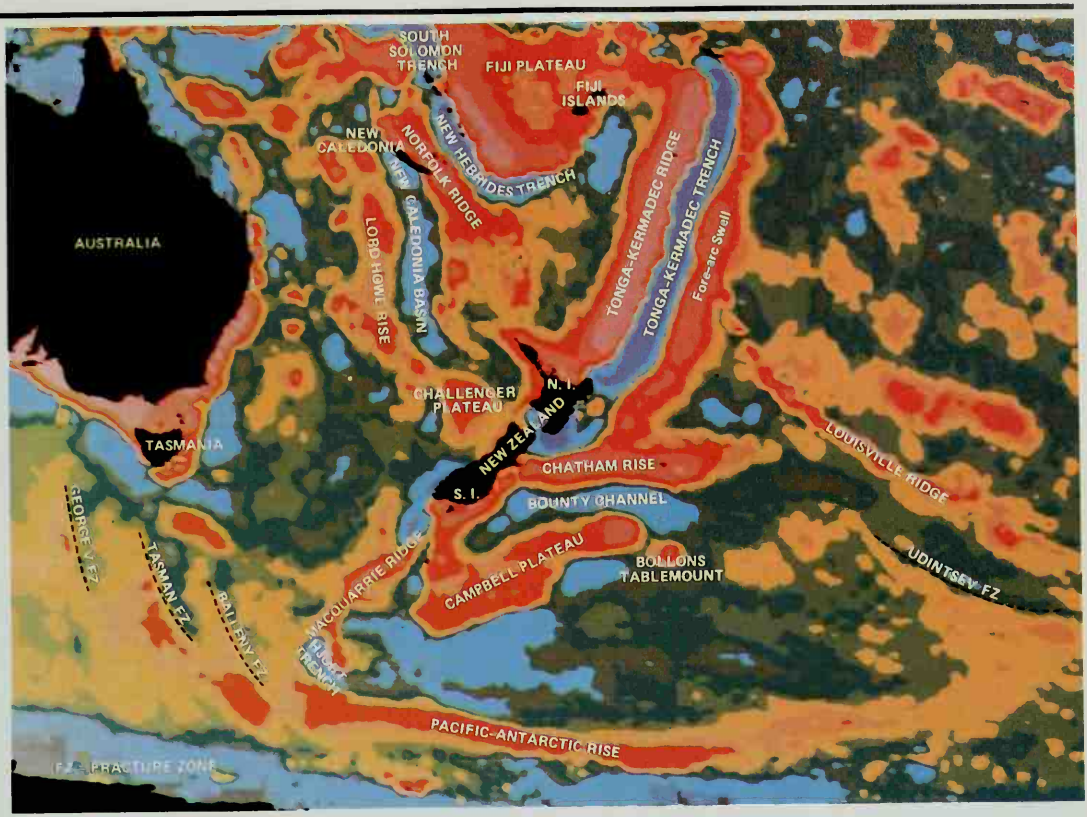
The oceans can be physically divided into three main elements, the continental shelf, the abyssal plains and the deep ocean trenches. The shallow, sloping continental shelves account for some 24 million square miles, or 12.5 per cent of the Earth's surface, extending from the coast out to sea, often for several tens of miles and normally at an angle of about one degree below the horizontal and ending abruptly at the shelf-break, which is usually found at a depth of about 400ft (130m). From there the slope steepens to angles varying from a few degrees to the almost vertical until the abyssal plains are reached.

The abyssal plains lie at an average depth of 12,000ft (3,700m), although some are much deeper. They have their own mountain ranges, plains and basins, with the mountains breaking the surface in places to form chains of volcanic islands such as Hawaii and Iceland. In the Atlantic there is a mountain chain running from Spitzbergen in the North almost as far south as Antarctica, with extensive plains lying either side at depths of over 16,000ft (4,900m). The largest of the latter is the Argentine Plain, with an area roughly equal to that of the continental USA, while the North American basin, the Vatteras Plain off Florida and the Sohm Plain south of Newfoundland are only slightly smaller.

There is no similar central spine in the Pacific. The East Pacific Rise runs south of Australia to swing northward parallel to South America as far as Mexico, enclosing the basins of the South Pacific, Chile and Peru. To the west are a series of wide basins containing the mountain-like Christmas Island and the Hawaiian chain. The ocean floor becomes even more complex near Japan, where huge island arcs form volcanic mountains interspersed by deep trenches, and in the area of the Marianas, Fiji and Kermadec-Tonga it is more complex than the Rockies and the Himalayas combined. A further feature of the abyssal plains are guyots, truncated, flat-topped volcanoes, of which at least 2,000 exist in the Pacific, with many more elsewhere.

Plunging to three times the depth of the abyssal plains are the deep ocean trenches which form the hadal zone (from the Greek hades, or the underworld). Reaching depths of more than 21,000ft (6,400m) and up to 6,000 miles (10,000km) long, these are among the most extreme

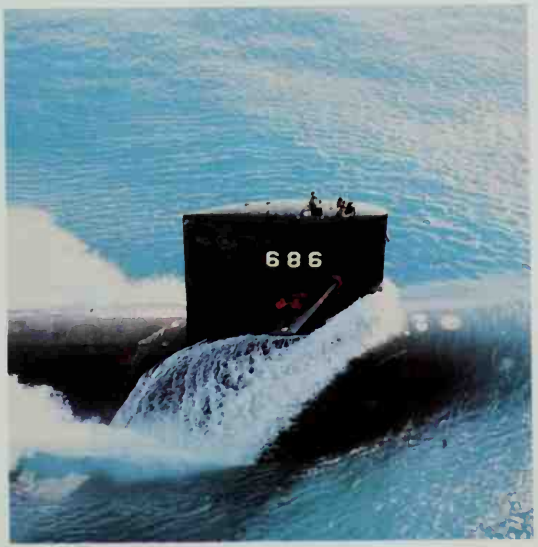
Right: USS *Mendel Rivers* (SSN 686) of the Los Angeles class can operate at depths of 1,500ft (450m), but even this prevents her from penetrating more than a small proportion of the oceans.



Above: Ocean-bed imagery taken from the SEASAT satellite. Average depth of the Tonga-Kermadec Trench to the northeast of New Zealand is 35,702ft (10,882m); it is 34 miles (55km) wide and 870 miles (1,400km) long. We have more detailed knowledge of the Moon's surface than of the depths of our own planet.

PACIFIC TRENCH DIMENSIONS

Trench	Depth	Width (approx)	Length (approx)
Aleutian	26,585ft/8,100m	43.5 miles/70km	1,429 miles/2,300km
Kurile	34,587ft/10,542m	74.6 miles/120km	1,367 miles/2,200km
Japan	32,185ft/9,810m	62.1 miles/100km	559 miles/900km
Mariana	36,200ft/11,034m	43.5 miles/70km	1,584 miles/2,550km
Tonga	35,702ft/10,882m	34.2 miles/55km	870 miles/1,400km
Peru-Chile	26,427ft/8,055m	43.5 miles/70km	3,666 miles/5,900km



environments on earth. Most occur around the edges of the Pacific, but there are others in the Indian and Atlantic Oceans.

PHYSICAL CHARACTERISTICS

The complexity of the ocean environment is exacerbated by its dynamic nature, equivalent in many ways to that of weather in the atmosphere. Its phenomena are difficult to predict or characterise, particularly because only a few of them, such as surface-wave activity, ice, tidal effects and local weather, can be observed by the human eye.

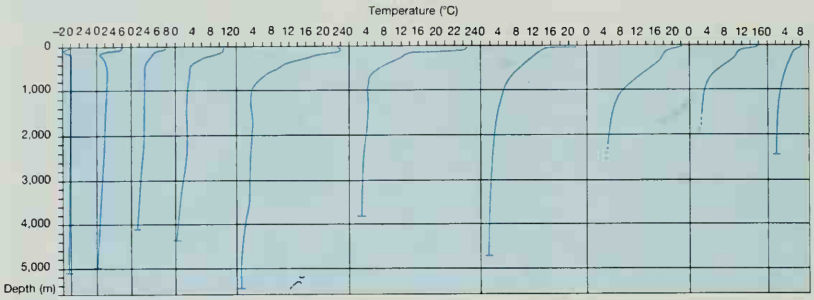
Among the better known characteristics of the oceans are that they contain many dissolved chemicals, including, of course, salt (sodium chloride), and that

MAJOR CONSTITUENTS OF SEAWATER

Substance	Symbol	Per cent
Sodium	Na	30.62
Magnesium	Mg	3.68
Calcium	Ca	1.18
Potassium	K	1.10
Strontium	Sr	0.02
Chloride	Cl	55.07
Sulphate	SO_4	7.72
Bicarbonate	HCO_3	0.40
Bromide	Br	0.19
Borate	H_2BO_3	0.01
Fluoride	F	0.01

Per cent = typical % by weight of major constituents

Atlantic temperature profile



Above: Vertical temperature distribution at stations along an Atlantic meridian. A surface layer of widely varying depth is heated by solar radiation. Below this layer the temperature falls with depth, in layers sometimes only 2in (5cm) wide, before the thermocline, where it falls rapidly with depth until it stabilises and decreases evenly to the bottom.

Above: Knowledge of sound velocity is essential to an ASW tactician and this Expendable Sound Velocimeter (XSV) is used by surface ships to measure such velocities to an accuracy of ±0.82ft/sec (0.25m/sec) down to a depth of 6,560ft (2,000m). Data is read directly into an on-board computer for storage, processing and analysis.

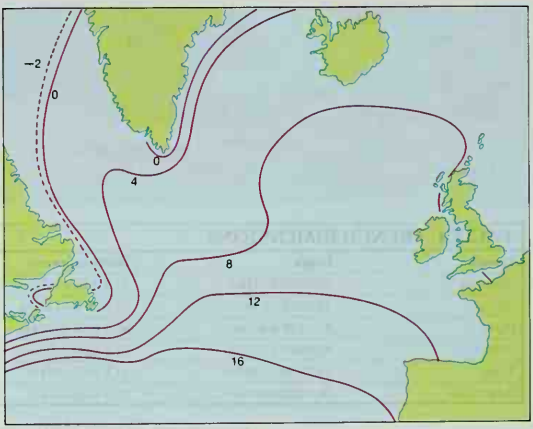
pressure increases with depth. There are, however, many variations in salinity (haloclines) and temperature (thermoclines), sub-surface currents, counter-currents and waves, the topography and nature of the ocean floor, and the existence of macro- and micro-organisms. Finally, man-made noises such as those caused by other ships, oil drilling and harbour activity affect the acoustical and optical properties of the waters that constitute the ocean environment.

The ocean is virtually opaque to most forms of radiant energy, but one exception is acoustic energy, which can travel great distances under water. The exact speed of sound in water depends upon the precise combination of temperature, pressure and salinity, but an average speed is about 4,757ft/sec (1,450m/sec), some four times faster than the speed of sound in air. Underwater sound transmissions are reflected by any solid object and a sensitive receiver can detect any echoes. Unfortunately, the science of sonar is by no means a simple one and the detection of an echo is just the start in a laborious process of trying to decide just where the reflecting body is and what it might be.

TEMPERATURE STRUCTURE

One of the principal factors governing the behaviour of the ocean is its temperature structure. Solar radiation heats the surface layer, the depth of which varies from tens of metres near the Equator to more than 100 metres in the high latitudes; below that the temperature then falls with depth in layers as little as two inches (5cm) thick to a layer where it falls fairly sharply with depth (the thermocline) and then decreases at a more gradual and even rate to the bottom. The depth at which the permanent thermocline is found varies from 984-1,312ft (300-400m) in equatorial areas to 1,640-3,280ft (500-1,000m) in sub-tropical areas. There is also a seasonal thermocline above the permanent thermocline and even, in some areas, a diurnal thermocline known more prosaically as the afternoon effect from the time of day it occurs.

Atlantic surface temperatures



Below: Surface temperature variations in the North Atlantic. A chart like this would be of limited value to a submariner, who needs up-to-date knowledge on the precise conditions in which he is operating. He must have detailed local information on variable factors such as temperature and salinity to enable him to fight his submarine effectively.

Left: The oceans appear at first sight to be a simple, homogeneous mass of water; in fact they form a very complex environment requiring as least as much study as atmospheric meteorology.

The thermoclines separate waters of slightly different densities, and a variety of organic and inorganic particulates tend to concentrate in them since they lack the energy to fall further. Inorganic substances include the material deposited either deliberately or naturally from the land, products of erosion of both the land and the ocean bed, and general debris. Organic objects in the thermoclines are mainly planktonic organisms which attract fish and shrimps in large numbers.

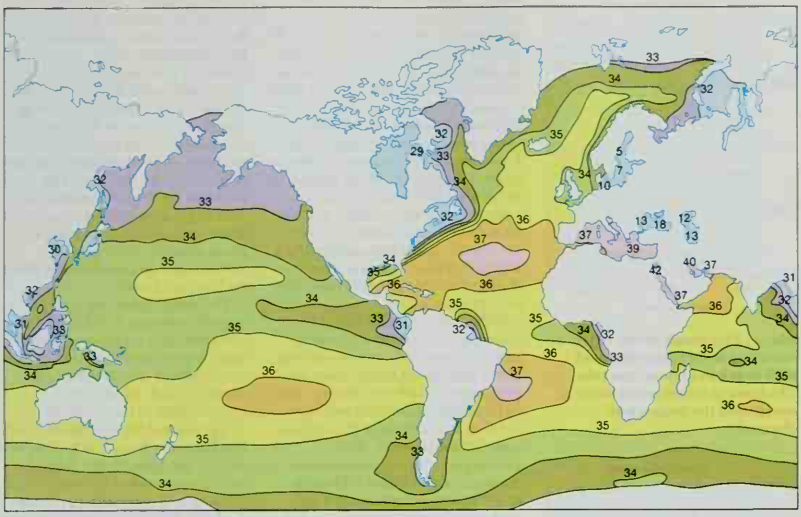
SALINITY

The normal saline concentration in the open ocean varies between 32 and 37 parts per thousand (ppt). The variations are the consequence of a number of competing processes, including concentrating effects such as evaporation and ice-floe formation, and diluting effects such as rainfall, river run-off and melting ice.

Variations in salinity have considerable operational significance for submariners, since submarines ballasted and trimmed for salt-water operations will ride deeper in fresh water, which is not as dense, and when diving will submerge before the main ballast tanks are totally full. Thus, operations off major estuaries or in fjords, where the water is much less saline, have to be planned with particular care. Conversely, some seas are much more saline, for example, the Baltic, and thus much denser.

A major submarine hazard occurs where sharp salinity gradients are associated with sharp

Surface slainity



Above: Salinity variations have operational significance for submariners and are the consequence of factors such as evaporation and ice-flow formations which increase salinity, and rainfall, river run-off and melting ice which reduce it.

temperature gradients as this combination can produce severe underwater turbulence. It is thought that such an effect was at least partially responsible for the loss of the USS *Thresher*, which went to sea on post-overhaul trials in April 1963 and was about 220 miles (354km) east of Cape Cod when she was driven down to a depth where catastrophic hull failure occurred. In August 1963 the bathyscaphe *Trieste* found the wreck at a depth of 8,500ft (2,590m) and was able to photograph compressed elements of the ill-fated submarine.

Salinity is one of the less significant factors affecting sound propagation, its velocity being changed by 4.3ft/sec (1.31m per second) per 1ppt change. However, in the turbulent areas mentioned above, where sharp salinity gradients are coupled with sharp temperature changes, there is also a marked refraction of sound energy.

PRESSURE EFFECTS

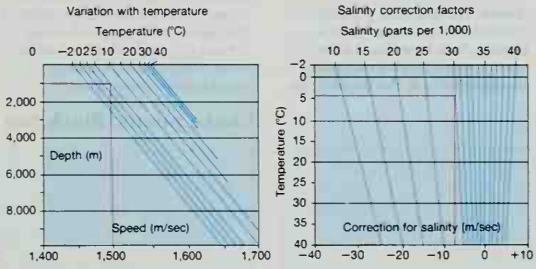
Pressure increases with depth in a simple relationship and at a rate determined by the salinity. In seawater pressure increases by 44.45lb/sq in (3.13kg/cm^2) for every 100ft of depth, but the increase is 43.5lb/sq in (3.06kg/cm^2) in fresh water.

Right: Warm tropical water drifts towards the poles and in return cool polar water flows towards the equator. The cold water currents start as surface flows but gradually sink to the bottom.

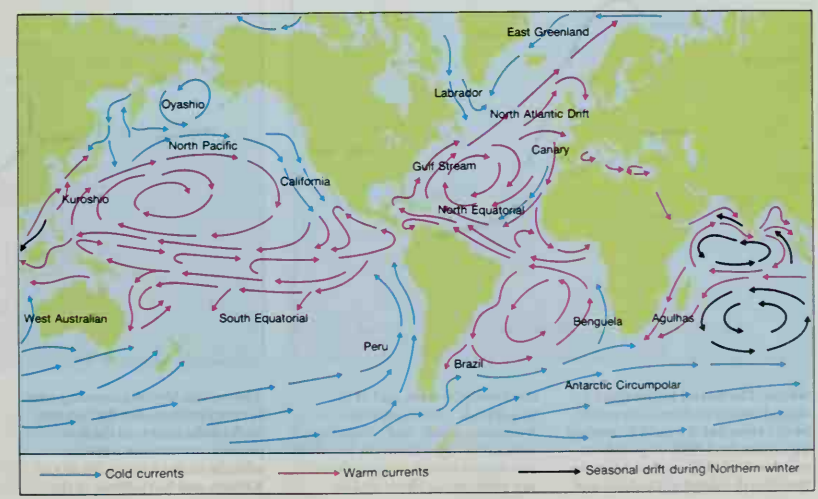
Below: Salinity varies from 32 to 37 parts per thousand (ppt), but can fall to 23ppt in fjords. The diagram shows the speed of sound in seawater for a salinity level of 35ppt; at 3,228ft (948m) and 5°C, for example, sound velocity is 4,904ft/sec (1,494m/sec).

Below: Salinity levels vary: the diagram shows the correction factors. If the salinity level is actually 30ppt, the speed of sound is 4,904ft/sec (1,494m/sec) minus 26ft/sec (7.9m/sec), giving an actual speed of 4,878ft/sec (1,486m/sec).

Sound propagation



Major currents



BATHYMETRIC EFFECTS

The bottom of the ocean can have two serious effects on anti-submarine warfare. If the bottom topography is irregular and rocky the complexity of the echoes returned may enable a submarine hugging the bottom to escape detection. This effect is known as reverberation.

Where the ocean bottom irregularities are sufficiently marked a submarine can shelter in the shadow of hills, an illustration of the fact that the more is known about the ocean bed from oceanographic survey the more successfully will submarines be able to make use of the effect.

For the submariner a knowledge of the ocean bed means more than just being able to take advantage of it to hide from the enemy's sonar. For him a knowledge of the continental shelf is vital as he must climb over the slope and the shelf proper on his return from a deep ocean patrol. Ballistic missile submarines patrol either the open ocean or under the ice cap and are unlikely to need detailed bathymetric information of such areas, but attack submarines need both such information and that for the bottom topography in operational areas such as the 1,000-fathom (1,820m) choke-points.

SURFACE EFFECTS

The main effect of surface currents is on sonobuoys, which will be dispersed from the impact point with resultant distortion of the accuracy of fixes on a target. Further, under certain conditions sonbuoys moving with a current will give the impression that a stationary target is moving in the reverse direction to that of the current.

Surface waves have a variety of effects, and really severe

conditions may prevent the launching or recovery of helicopters and variable-depth and towed sonar arrays. Similarly, waves can degrade the performance of air-dropped sonobuoys, which suffer a 75 per cent transmission loss in 10ft (3.04m) waves and a total loss in 15ft (4.57m) waves. In addition, high sea states can cause a mixing of water on either side of the thermocline, giving a relatively thick layer of isothermal water which increases the noise problem for the sonar systems. Finally, breaking waves add to the ambient noise level, again compounding the sonar problem.

Weather also has its effects. Thunder, rain on the surface and associated wave activity all add to the ambient noise level over a very considerable area, decreasing the signal:noise ratio at receivers and thus reducing target discrimination.

SOUND WAVES

The result of the layering of the oceans and the continuous variations of velocity with depth is that the paths of sound waves in the ocean are never straight lines, but are arcs of circles in accordance with Snell's Law, which was discovered in relation to light rays but is equally applicable to sound waves in water. The consequence of Snell's Law is that where a sound wave travels from one density layer to another its path is bent towards the normal when it enters a layer of greater density and away from it if the density is lower. Further, where density is altered gradually the sound wave will be bent, or refracted, similarly. In addition, sound waves are scattered by the barriers of the oceanic medium at the surface and the bottom, so that the circular arc trajectories converge, leaving large volumes of the ocean simply impenetrable by sound from a given source. This phenomenon, known as the convergence zone, is quite independent of the power intensity of the sound wave. A submarine in such a zone will not be detected even when it is very close to the sonar transmitter and a number of warships were lost during World War II because of the convergence effect.

If the acoustic transmitter is depressed below the horizontal and the water column is more than 2,000 fathoms (3,650m) deep the propagation path will bottom-out in the deep sound duct and be refracted, returning to the surface some distance away. This convergence zone phenomenon occurs at about 38nm (70km) in tropical waters and about 22nm (40km) in northern waters and the Mediterranean, and the width of the zones is about 5-10 per cent of the range. Increases in sound intensity of 15-20dB in the convergence zone are common.

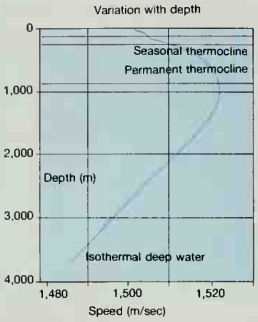
The transmission profile and the length of the convergence zone are also influenced by the depth of the water column and of the acoustic source and receiver. In shallower waters the type of bottom and its topography can affect the quality of the signal, with a smooth rocky bottom giving good reflection but mud, slime or sand causing considerable attenuation.

The ocean itself is inherently noisy because of the abundance of marine life, seismic disturbances from underwater volcanoes and the crashing of waves. In addition, there is a growing amount of man-made noise from merchant ship activities and third-nation naval vessels, as well as the increasing use of seismic exploration methods and offshore drilling on the sea floor. The problem for the anti-submarine sonar operator is to recognise and screen out all those unwanted noise sources, whereas the submarine commander uses them for his own benefit.

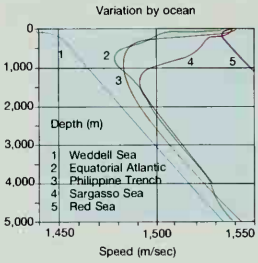
The deep scattering layer is usually composed of a thick layer and three sub-layers consisting of microscopic photoplankton and zooplankton which reflect and scatter sound waves. The composition of the layer, its thickness and the depths at which it occurs vary from area to area, and also by the time of day. Sound waves projected at or near the vertical will generally penetrate the layer, but if projected at or near the horizontal to the layer they will be scattered and diffracted. The effects of the deep scattering layer can be overcome by optimising the relationship of frequency, pulse length and power output, but often the sonar operator will have little choice but to revert to passive methods.

The thermocline has a major influence on ASW as it affects the velocity of sound and in the permanent thermocline the velocity reaches a minimum. This layer of minimum velocity, known as the deep sound channel, has a

Sound propagation



Above: This graph shows a typical variation in the speed of sound with depth in a temperate area. The layer of minimum velocity is designated the deep sound channel.

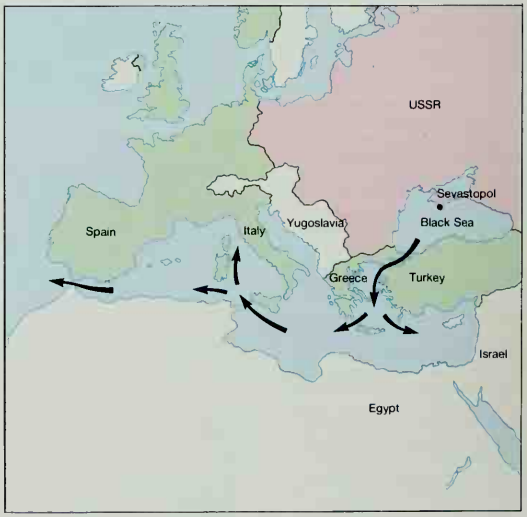


Above: The different acoustic characteristics of the world's oceans. Note how close to the surface is the level of minimum sound velocity in the Weddel Sea.

Choke points: Baltic exits

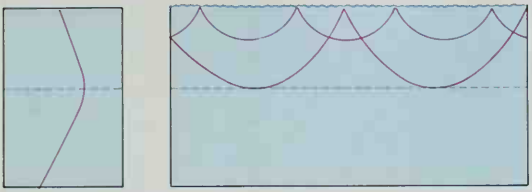
Above: The Soviet Baltic Fleet's operations in its home sea would be of value, but it would be bottled up unless the USSR were able to gain control of the sound between the Danish Island of Zealand and the Swedish coast, and of the Skagerrak. The importance of Sweden is clear, and recent Soviet submarine operations in Swedish territorial waters suggest there are plans to use them in war.

Choke points: Black Sea and Mediterranean

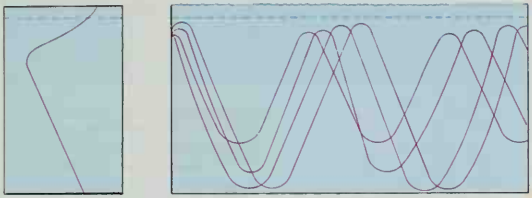


Above: The Mediterranean poses severe problems for the Soviets, with choke points in the Bosphorus, around the Aegean islands, in the Aegean Straits of Kithera and Karpathos, in the Sicilian Channel and in the Straits of Gibraltar. The Soviet Mediterranean squadron normally includes up to eight submarines, which would be primary targets for NATO ASW forces.

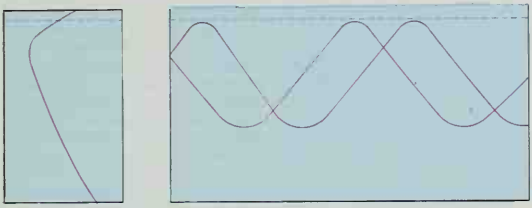
Surface duct



Convergence zones

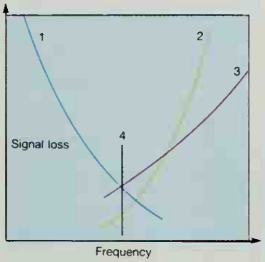


Underwater sound channel

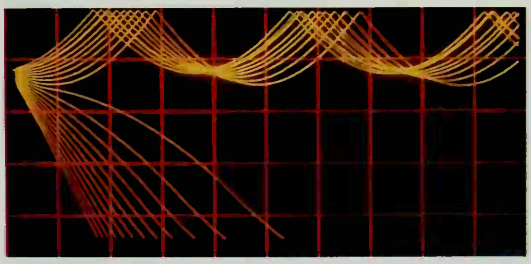


Above: Profiles on the left show how sound velocity varies with depth; ray diagrams are on the right. The surface duct is formed by reflection from the surface and the thermodine. Convergence zones widen with distance (centre) and shadow zones narrow. Underwater sound channel is formed by sound velocity increasing with temperature above it and hydrostatic pressure below.

Surface duct energy loss



Left: Of the three major causes of signal attenuation, the first (1), the diffracting effect of the seawater medium, reduces as frequency increases; absorbtion loss (2), due to the sound wave transferring a certain amount of energy to the water, and rises with frequency. Scattering losses due to the sound wave striking and being reflected by foreign bodies in the water rise with frequency, the optimum frequency (4) being that at which the average loss is lowest.



Above: The fact that sound waves do not travel in straight lines in seawater is shown clearly by this typical sound propagation trace, illustrating how sound energy transmitted at various angles from an active sonar transducer spreads through the ocean. As well as areas where a target will be hit by the radiated energy, there are extensive zones where it will be safe from detection.

variety of effects, one of which is that a sound signal can travel in it for more than 620 miles (1,000km) and still have one per cent of the energy it had 6.2 miles (10km) from the source. It is at least theoretically possible that a submarine could operate in this deep sound channel, exploiting this effect to achieve very long range detection.

Above the surface is an atmospheric duct as much as 600ft (183m) thick which can affect the electro-magnetic performance of ASW aircraft. If both transmitter and receiver are within the duct communications are unlikely to be affected; indeed, range and detection may well be enhanced. If, however, the aircraft is above the duct not only may its radar fail to detect targets on the surface – periscope, sail or snorkel – but its receivers could also fail to pick up signals from sonobuoys.

OCEANOGRAPHIC RESEARCH

The oceans of the world are vast and imperfectly understood; they are also of vital strategic importance. Consequently, many navies devote resources to oceanographic research and intelligence gathering, although the actual number of ships is surprisingly small in view of the size of the task. The Soviet Union has some 56 oceanographic research ships (24 of which are civilian crewed), 130 surveying ships (including 35 civilian) and an unknown number of deep-diving craft, four of which are known to be associated with the two India class submarines. Against this US naval resources include 14 oceanographic research ships, nine surveying ships and seven deep submergence vehicles, although other in-service ships are used in research activities from time to time. Some aircraft are also used and there are a further four oceanographic and hydrographic survey ships in the National Oceanographic and Atmospheric Administration. The world's third strongest navy – the Royal Navy – has a meagre four ocean-going, five coastal and one inshore surveying vessels, although a new and unusual ship, HMS *Challenger*, was commissioned in 1985. Described as a Seabed Operations Tender, the *Challenger* has a full-load displacement of 7,185 tons and is crewed by the Royal Navy, as opposed to the Royal Fleet Auxiliary. There can be no doubt that much greater resources need to be devoted to underwater research, not only to increase our knowledge of the oceans but also, from a military standpoint, to enable submarine operations to be conducted more effectively and with better safety margins.

Below: The fundamentally alien nature of the underwater environment is illustrated clearly by this picture of a diver undertaking a relatively simple photographic task. What would be a very straightforward assignment above water has become very complicated below the surface, requiring breathing apparatus for the diver and special protection for both man and equipment.

Design and Construction

As with any weapon system the design of a submarine starts with the naval staff requirement, which must state what role the vessel is designed to fulfil, its weapons and sensor fit and the performance parameters it must meet. Until the mid-1960s the primary strategic role of the submarine was to attack hostile naval surface vessels and maritime logistic traffic. This role still exists, but the evolution of submarine-launched ballistic and cruise missiles has brought a further strategic role, that of striking directly at targets in the enemy's homeland.

The modern submarine's third main role is to attack other submarines and surface shipping. While nuclear-powered attack submarines (SSNs) are most effective in this role, the conventionally powered diesel-electric submarine still has a major role and many hundreds are operational with some 39 navies, employed on attack missions, general patrol duties and clandestine special operations.

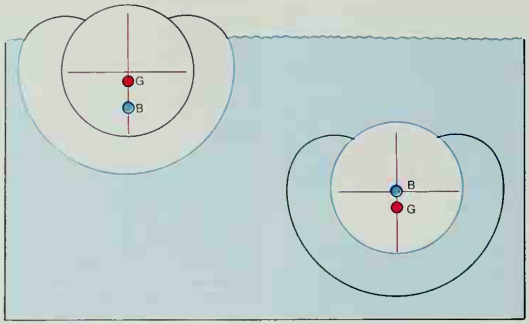
As nuclear-powered submarines are so expensive in capital cost and in their requirement for specialised manpower the majority of the world's navies will continue to operate non-nuclear submarines for the foreseeable future. All submarines, however, no matter what their propulsion system or role, have many design constraints in common.

DESIGN

Just as important as the advent of nuclear propulsion has been the revolution in submarine hull design pioneered in the 1950s by USS *Albacore* (AGSS-569). The long, narrow, highly streamlined hulls introduced by the German Type XXI of World War II proved unable to cope with the increased power becoming available and in certain circumstances, particularly at speeds of over 12 knots, control could be lost altogether. USS *Nautilus* (SSN-571) for example, despite her nuclear powerplant, could not exceed 23.3 knots under water, but the diesel-electric powered *Albacore*, with a teardrop hull shape based on airship practice, cruciform tail empennage and single propeller, achieved a sustained underwater speed of 26 knots in her original form and later, with contra-rotating propellers and silver-zinc batteries, became capable of an astonishing 33 knots. Not surprisingly, she has set the pattern for the majority of subsequent Western hull designs. Contemporary pressure hull designs are, however, less fat than that of the *Albacore*, because a parallel mid-body is almost as efficient if the forward and after ends are properly designed, and a tubular body is much easier and cheaper to construct.

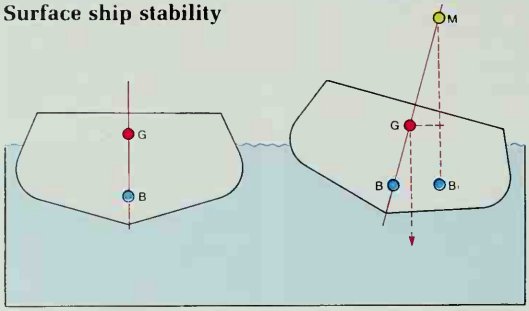
The design of any weapon system is inevitably the result of a number of compromises, but that of submarines involves a number

Surfaced and submerged displacement



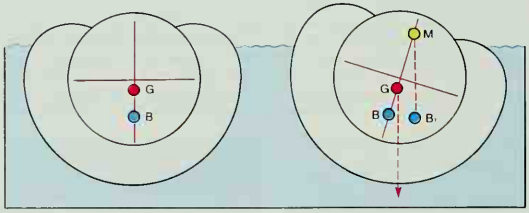
Left: A submarine's buoyancy depends on the volume of displaced water and is controlled by varying the volume of displacement. On the surface (left) the main ballast tanks are filled with air so the displaced water – the area within the heavy line – equals the weight of the submarine. When it is submerged (right) the main ballast tanks are filled with water; the submarine's weight is the same, but the volume of displaced water, again represented by the area within the heavy line, has been reduced, while the centre of buoyancy (B), the geometric centre of the volume of displaced water, has moved from below to above the centre of gravity (G).

Surface ship stability



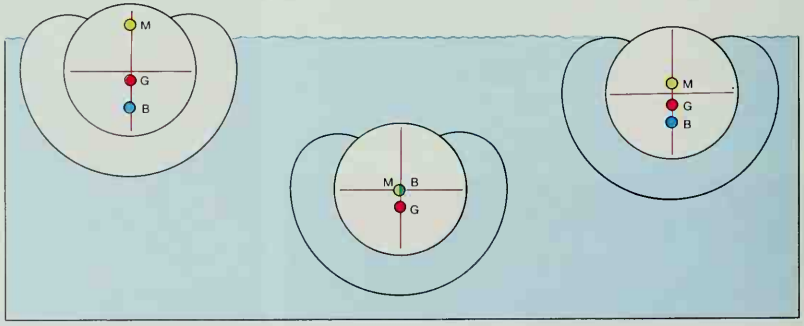
Left: When a surface ship lists (right) the centre of buoyancy, being at the centre of gravity of the displaced water, moves to B1, because the volume of displaced water to the left of G has decreased, while that to the right of G has increased. A vertical line through B1 now intersects the original line BG at M; the distance GM being termed the metacentric height. When M is above G the metacentric height is positive and the moment arm (horizontal broken line) tends to return the vessel to its original position, so the vessel is stable.

Surfaced submarine stability



Left: A surfaced submarine presents much the same situation as a surface ship. However, the three points B, G and M, although in the same relative positions, are much closer together; further, since the shape of a submarine is for practical purposes cylindrical there is no resistance to the motion. Submarines therefore have a tendency to roll, making their motion on the surface uncomfortable.

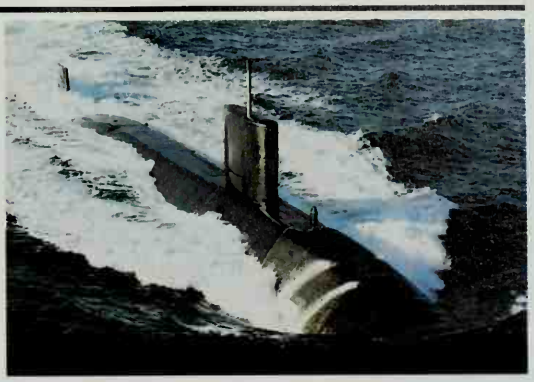
Effect of submergence



Above: When a surface ship lists its centre of buoyancy (B) shifts because of the different shape of the volume below the waterline. This does not happen in a submerged submarine because its entire volume is below the surface. For stability underwater it is necessary that the centre of gravity (G) be below the centre of buoyancy. As shown here, when the submarine is on the surface (left) B is below G, which is at a fixed point slightly below the centreline of the vessel, while M is well above. Then, as the submarine submerges (right), B and M approach each other until they meet on the centreline (centre). During this process the position of least stability is at the point when B and G coincide. This is not too serious during descent, but when surfacing the water ballast is ejected comparatively slowly by compressed air and the metacentric height (GM) may become negative and a list may occur. Most submarines have lever-operated, list-control valves which can restrict air to the high side and increase it to the low side.

G Centre of gravity
B Centre of buoyancy
M Metacentre

Above: HMS *Turbulent* surfacing in a level condition. At this stage her ballast state is as shown at the right of the bottom diagram on the opposite page, with M above the centreline and B below G.



Above right: HMS *Turbulent* running on the surface. In this state a submarine's stability depends on the position of her centre of gravity and her shape, above and below the waterline.

of particularly difficult problems. The most basic of these is that a submerged submarine must have neutral buoyancy and a centre of gravity lying below its centre of buoyancy, and every element in the craft affects their locations. The naval staff requirement must state the extremes in which the submarine must be able to operate, in particular the density of the seawater likely to be encountered. The distribution of weight within the submarine is crucial to its stability and the expenditure of items such as fuel, stores, weapons and provisions must be taken into account. The compressibility of the hull is a further factor, since in a deep-diving submarine this could result in a loss of buoyancy of several tons at depth.

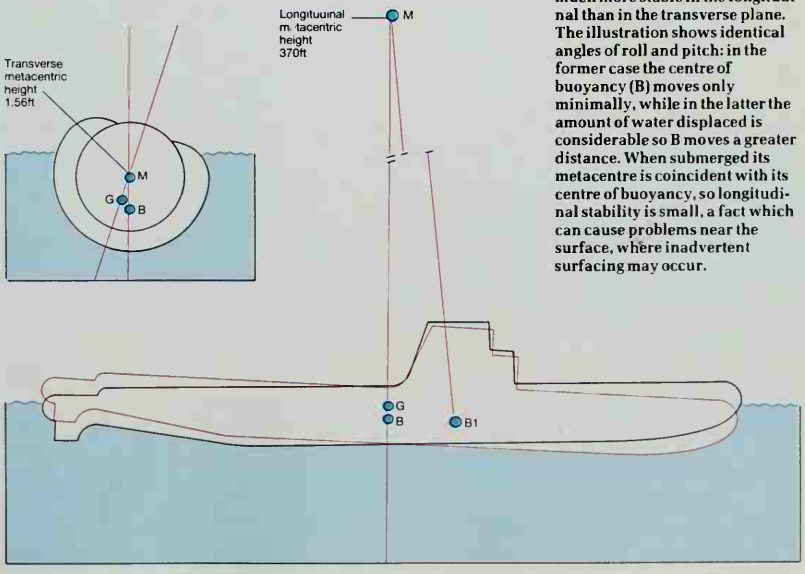
Diving depth is obviously a crucial tactical consideration, because depth provides shelter, especially if the submarine can go deep enough to exploit the acoustic properties of the sea to thwart detection devices. Depth also gives a safety margin in high speed manoeuvres. Actual details are highly classified, but open source figures for some representative nuclear-powered attack submarines give a general indication of normal operating depths for comparative purposes: USS Los Angeles 1,475ft (450m); the Soviet Victor III 1,300ft (400m); and the French Rubis 980ft (300m). Depth performance is becoming more important as the anti-submarine threat increases and has stimulated extensive research and development into materials.

A lot of research is devoted to the subject of hydrodynamic efficiency. The total drag of a submerged submarine has three elements: skin friction, form drag and appendage drag. As was so successfully demonstrated by the *Albacore*, a solid-of-revolution form, and especially one without a parallel mid-body, has the minimum skin friction, although in practical terms a cylindrical mid-body provides a satisfactory compromise. As with an aircraft, skin friction is directly proportional to surface, or wetted area – in other words, the bigger the hull the greater the drag.

Form drag is usually only between two and four per cent of the total for a solid-of-revolution, but roughness of the hull can significantly affect resistance, and a badly finished hull or one with poorly designed or positioned flood openings will have significantly greater drag than one with a good finish, as well as making much more underwater

Right: The Tench class diesel-electric submarine USS *Pickerel* (SS 524), surfaces at a 48° angle from a depth of 150ft (46m) during a test programme off the Pacific island of Oahu on March 1, 1952.

Longitudinal stability



Left: A surfaced submarine is much more stable in the longitudinal than in the transverse plane. The illustration shows identical angles of roll and pitch: in the former case the centre of buoyancy (B) moves only minimally, while in the latter the amount of water displaced is considerable so B moves a greater distance. When submerged its metacentre is coincident with its centre of buoyancy, so longitudinal stability is small, a fact which can cause problems near the surface, where inadvertent surfacing may occur.

noise and so being easier to detect. Finally, appendages always add drag, no matter how well they are designed, sometimes equivalent to more than half the total bare hull resistance. Laminar flow has been tried, but while it offers apparent drag reductions of over 50 per cent putting the theories into practice has been thwarted so far by the impurities of seawater.

Streamlining has been the rule since the wartime Type XXI boats, but great attention is now being paid to the nature of the hull surface: special paints can reduce friction and thus either increase speed or reduce the amount of power required for a given speed. Releasing polymers around the hull is also used to increase speed for short periods, and it has been reported that the exteriors of Soviet submarines are coated with a compliant covering, derived from research into marine animals such as dolphins and killer whales, which combines suction and boundary-layer pressure equalisation.

Further development based on the same research may lead to devices to modify shapes to match the boat's speed by, for example, progressively retracting the hydroplanes or changing the shape of the fin as speed increases. And findings from such studies may account for the very interesting shape of the latest Soviet submarines, which have bulbous bows, similar in shape to the front end of a whale, and sails which are smaller than those on Western submarines and less angular in shape, merging rather more smoothly into the hull; they appear more akin to the fin of marine animals than do those on Westerm submarines.

Manoeuvrability is obviously of great importance to a submarine and again the *Albacore* had a great effect upon all subsequent designs. Her short hull gave substantially improved manoeuvrability over the then current long, narrow designs, and during trials she was able to turn at 3°/sec, much faster than conventional submarines of the time but a rate probably comfortably exceeded by current types.

High speed and efficient control systems enable modern submarines to be manoeuvred in three dimensions, like aircraft. A turn within four times the submarine's length is feasible and ascents and descents at rates of several hundred feet per minute are possible. Indeed, such aerodynamic problems as sideslip in turns have become important and the size and shape of the fin is a critical factor.

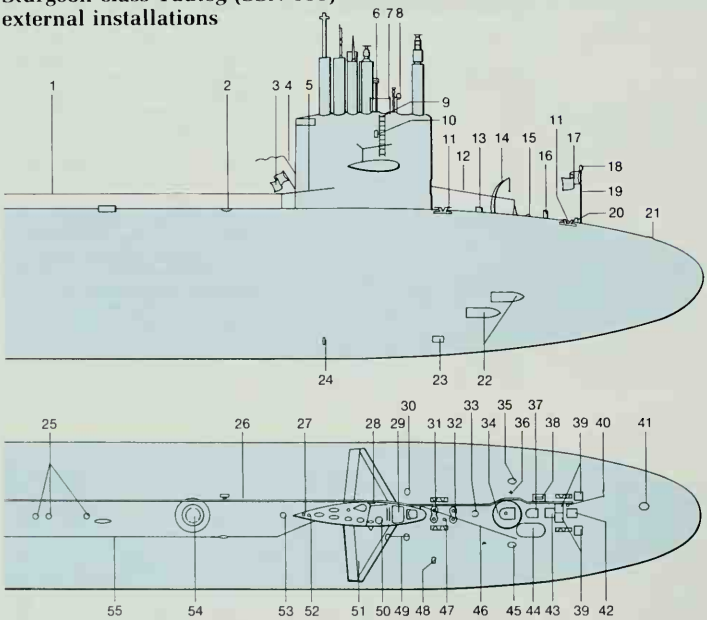
The major control surfaces are the hydroplanes. The original Holland submarines did not have forward hydroplanes; these were added later in order to maintain an even keel during a dive, but with the disappearance of such a requirement they have been retained for diving control and trimming, particularly at periscope depth. IKL-designed submarines have extendable scythe-shaped bow hydroplanes, set at a fixed angle: the control force required is achieved by varying the amount of area exposed, and the two planes are set at opposing angles, one being used for descent and the other for ascent. Other submarines are fitted with bow-mounted retractable or foldable hydroplanes which pivot to achieve upward or downward motion.

Some navies, such as those of the USA, Japan and France, use fin-mounted planes. While these may offer advantages in terms of manoeuvrability, they need to be capable of rotation to the vertical for breaking through ice if it is necessary to operate in the Arctic. Those on the Los Angeles class boats cannot do so, which is a serious tactical limitation now that under-ice operations have become so necessary to counter the growing Soviet use of the Arctic, and in 1985 US Secretary of Defense Weinberger announced that the planes would be moved to the bows on future members of the Los Angeles class.

Below: The apparently smooth exterior of a modern submarine actually houses dozens of hatches, connections, cleats and other items, compounding the underwater noise problem.

Right: USS *Richard B. Russell* (SSN 687), a Sturgeon class attack submarine which is identical to the USS Tautog, whose external installations are identified and described below.

Sturgeon class *Tautog* (SSN 639) external installations



1 Portable emergency lifeline
2 Portable cleats (port and starboard)
3 Ensign No 11
4 No 7 commissioning pennant
5 HP air external charging connection
6 Identification beacon light
7 Portable lifeline
8 Masthead light
9 Portable ladder (P&S)
10 Sidelight (P&S)
11 Hinged cleat (P&S)
12 Portable emergency lifeline
13 Retractable capstan
14 Portable davit
15 Towing eye
16 Underwater log
17 No 7 union jack
18 Forward anchor light
19 Portable jackstaff
20 Hinged cleat (P&S)
21 Sonar sphere access
22 Torpedo tube shutters (P&S)
23 Torpedo ejection pump shutter (P&S)
24 Underwater log
25 Salvage air connections
26 Safety track
27 Ventilation exhaust
28 Sidelight (P&S)
29 Bridge
30 Access hatch
31 Main vent valves Nos 3A and 3B
32 Main vent valves Nos 2A and 2B
33 Retractable capstan
34 Escape trunk
35 Main vent valve No 1B
36 Capstan control
37 Escape hatch
38 Underwater log
39 Line locker access hatches
40 Salvage air connection
41 Sonar sphere access
42 Hinged towing fairlead
43 Access hatch
44 Messenger buoy
45 Main vent valve No 1A
46 Diesel lubricating oil fill connection
47 Salvage air connection
48 Signal ejector
49 Access hatches
50 Lookout station
51 Portable lifeline
52 Diesel exhaust
53 Salvage air connection
54 Weapons shipping hatch
55 Portable emergency lifeline

Right: This latest Soviet Akula class nuclear-powered attack submarine shows the smaller, less angular and more streamlined shape of Soviet sails, believed to be derived from research on marine animals such as dolphins.

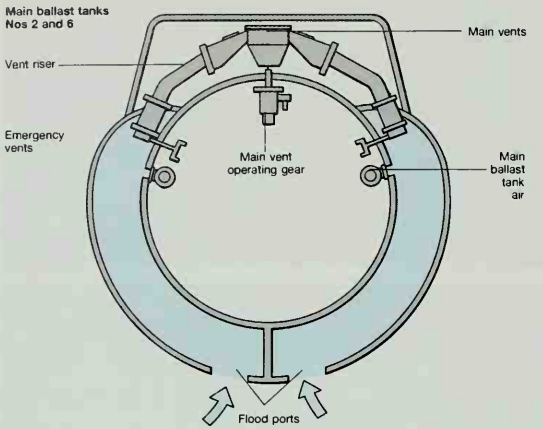
The design of the after end of the submarine and the correlation of hull shape, propeller and control surfaces is also important. At one stage in the mid-1940s the after control surfaces were placed astern of the propeller and this was the original layout in the *Albacore*, but the majority of modern submarines have cruciform stern empennages, with horizontal and vertical control surfaces forward of the propeller. In the American Los Angeles and Ohio classes the after horizontal hydroplanes are fitted with vertical endplates, both to improve control and also to serve as housings for hydrophones.

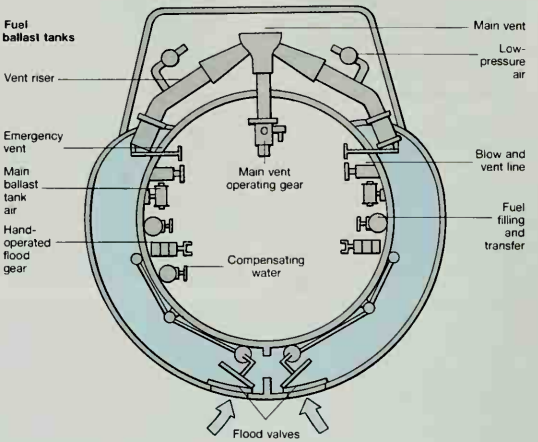
The latest Swedish Näcken and Dutch Walrus classes, on the other hand, have indexed, X-shaped empennages. This concept was first tested on the *Albacore* in 1961 and proved far superior to any of the previous designs. The X-shape is 42 per cent more efficient in all major operating directions than a

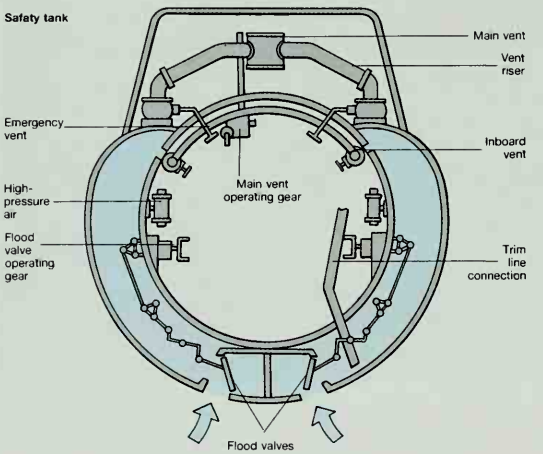
Right: The Sturgeon class USS *Spadefish* (SSN 688) with her fin-mounted forward hydroplanes rotated to the vertical to penetrate ice. Such manoeuvres are not possible with Los Angeles boats.

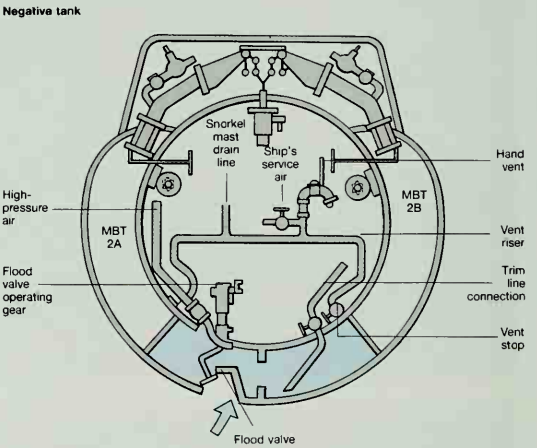
Below: Soviet Oscar class SSGN showing the tiles which cover her hull; some are missing. These are believed to have both acoustic absorbing and boundary-layer pressure equalisation effects.

Guppy type submarine tank arrangements









Top: To dive a submarine involves opening the vents, allowing seawater to enter through flood ports. The water is expelled by compressed air to surface.

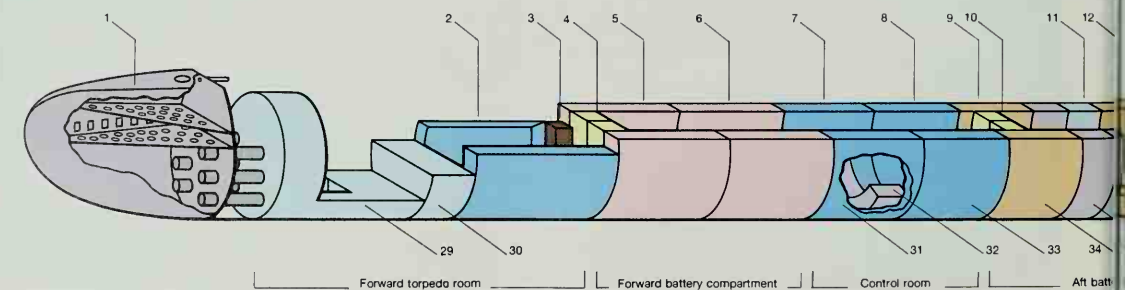
Above: Blowing the safety tank when submerged restores positive buoyancy quickly. It is located amidships to minimise the effect on fore-and-aft trim.

Top: Fuel ballast tanks must be full before submerging. When fuel is expended seawater is admitted, and allowed to flow between the tanks by limber holes.

Above: Quick diving can be achieved by flooding the negative buoyancy tank, which is also used to drain the snorkel mast during preparations for snorkelling.

- Main ballast tanks
- Variable ballast tanks
- Special ballast tanks
- Fuel ballast tanks
- Fuel oil tanks
- Lubricating oil
- Main engine sump
- Fresh water
- Sanitary tanks

1 Bow buoyancy tank (capacity 18 tons of seawater)
2 Main ballast tank No 1 (44.35t)
3 Sanitary tank No 1 (2.06t/537gallons)
4 Fresh water tanks Nos 1 and 2 (1,000g each)
5 Normal fuel oil tank No 1 (11,401g)
6 Normal fuel oil tank No 2 (13,122g)
7 Main ballast tank No 2A (32.98t)
8 Main ballast tank No 2C (32.98t)
9 Fuel ballast tank No 3A (37.37t/9,521g)
10 Fresh water tanks Nos 3 and 4 (1,000g each)
11 Auxiliary ballast tank No 1 (31t)
12 Fuel ballast tank No 4a (47.12t/12,045g)
13 Sanitary tank No 2 (2.57t/673g)
14 Fuel ballast tank No 5A (38.12t/9,729g)
15 Main ballast tank No 6A (35.4t)
16 Main engine sump No 1 (450g)
17 Main engine sump No 2 (450g)
18 Main ballast tank No 6C (35.4t)
19 Clean fuel oil tank No 1 (611g)
20 Collecting tank (2,993g)
21 Main engine sump



cruciform arrangement, and is also quieter and safer. In addition, the X-shape can be made more efficient hydrodynamically if individual blades are of a longer, narrower shape and, because they extend beyond the boundary layer into undisturbed water, of a smaller area. Finally, it is necessary that controls should not extend beyond the keel or the maximum horizontal breadth of the submarine and with the X-shape this can be achieved with ease. However, because of the complex relationship between steering and diving functions, such surfaces require computer-aided operation.

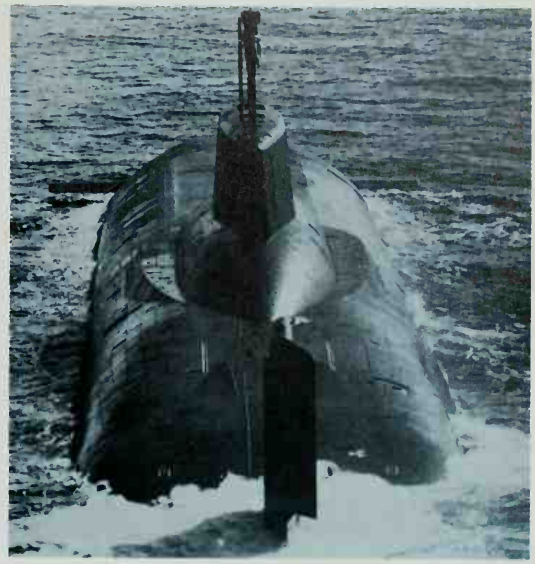
The submarine captain's greatest enemy is sonar and, apart from tactical methods of avoiding sonar detection, there are some passive measures which can be implemented at the design stage. The first is to make the submarine smaller and so a more difficult target, but it is difficult to fit the mass of weapons and sensors now considered essential into a small hull. Another technique is to shape the contours of the hull in such a way that the sonar beams are diffused. Finally, anechoic (sound absorbing) tiles can be used to coat the most critical parts of the submarine. These are already in use on Royal Navy submarines and on the latest Soviet submarines – one type of Soviet tile has the NATO designation Cluster Guard – and will be introduced on the next generation of US attack submarines.

CONSTRUCTION

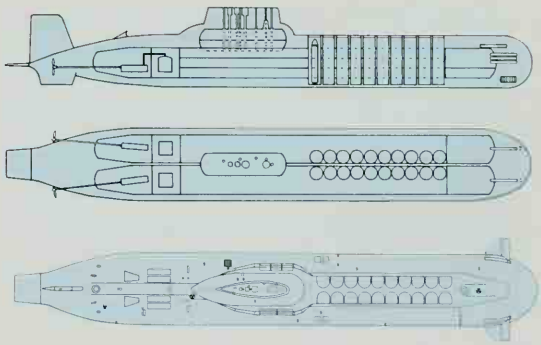
There are four main types of hull arrangement: single-hull, saddle-tank, double-hull and multi-hull. Single-hull submarines have their main ballast tanks mounted either externally at either end of the pressure hull, as in the US Navy's Los Angeles class, or within the hull itself. Saddle-tank submarines have their main ballast tanks mounted externally as streamlined additions to the pressure hull, as in the British Oberon class, with free-flooding holes at the bottom and vents at the top. Such main ballast tanks are sometimes used as additional fuel tanks with the fuel floating on top of the seawater, which extends the range considerably but reduces the reserve of buoyancy, an acceptable risk in time of war. A double-hull submarine has a complete or almost complete outer hull surrounding the pressure hull over most of its length. The space between the two hulls is used for main ballast tanks and external fuel stowage, the distance between them being dictated mainly by construction and access considerations.

The final possibility is to have two or even three pressure-hulls. The Dutch Dolfijn class submarines have three separate, interconnected hulls in a treble-bubble arrangement. The large upper hull contains the crew and most of the equipment, while below it and alongside each other are two smaller hulls, each containing machinery and stores. The advantage of this layout is that it gives great strength and the Dolfijn class boats can dive to 980ft (300m).

Such a submarine is difficult and expensive to construct and the Dutch did not pursue this idea in their later classes. The Soviet Navy, however, appears to have adopted a double-hull arrangement in its Typhoon class ballistic missile submarines and it is the consensus view in the West that these gigantic vessels have two complete, interconnected pressure hulls, each containing crew quarters and propulsion machinery, with a third, smaller pressurized section above and between them and directly under the sail for the command and control centre. The space for the missiles is between the two lower hulls and, most unusually, before instead of abaft the sail. Apart from spaciousness and habitability, such a submarine will have great survivability.



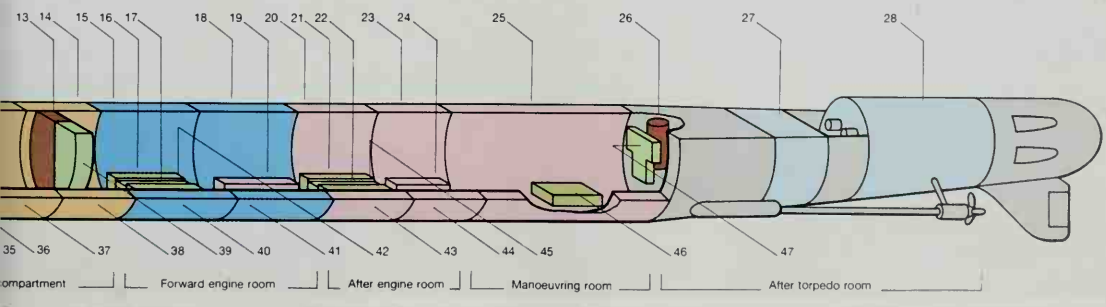
Typhoon class internal arrangement (conjectural)



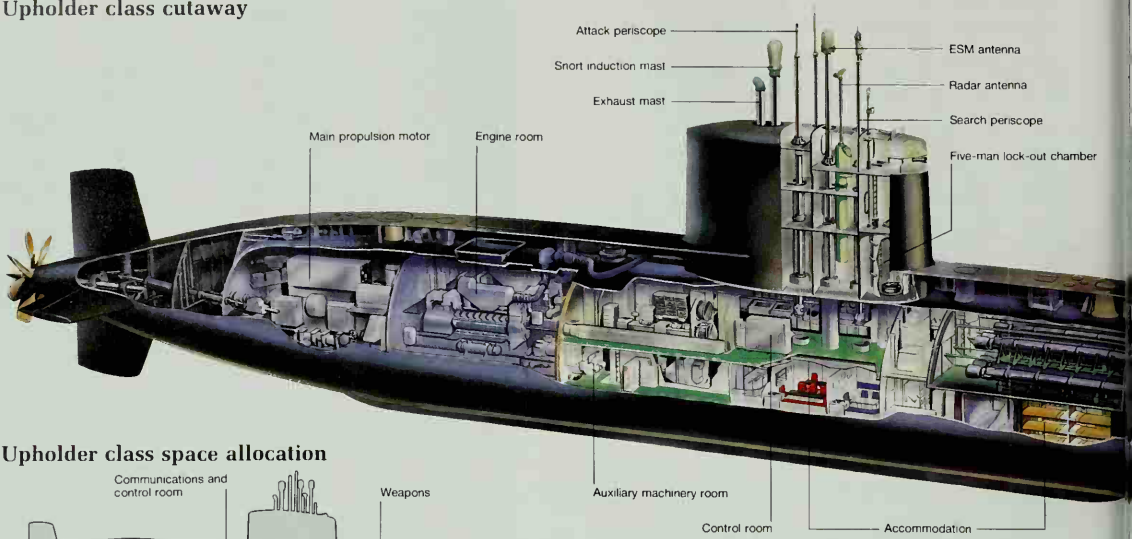
Top: The sheer size of the Soviet Typhoon SSBN took the West by surprise. One explanation of its considerable beam is that there may be two internal hulls.

Above: A possible interior layout of the Typhoon showing the side-by-side hulls containing missiles and a nuclear reactor, with a control centre above.

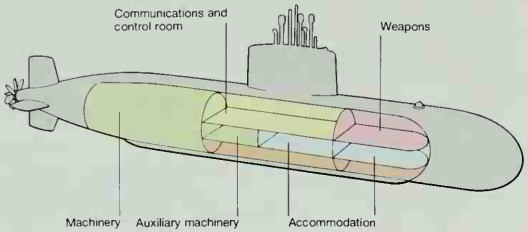
No 3 (450g)
22 Main engine sump No 4 (450g)
23 Normal fuel oil tank No 6 (15,201g)
24 Clean fuel oil tank No 2 (618g)
25 Normal fuel oil tank No 7 (10,599g)
26 Sanitary tank No 3 (0.87t/206g)
27 After water round torpedo tank (5t)
28 After trim tank (20t)
29 Forward trim tank (24t)
30 Water round torpedo tank (5t)
31 Main ballast tank No 2B (32.98t)
32 Negative tank (12t)
33 Main ballast tank No 2D (32.98t)
34 Fuel ballast tank No 3B (37.37t/9,521g)
35 Safety tank (23t)
36 Auxiliary ballast tank No 2 (31t)
37 Fuel ballast tank No 4B (47.12t/12,045g)
38 Fuel ballast tank No 5B (38.12t/9,729g)
39 Reserve lubrication oil tank (1,201g)
40 Main ballast tank No 6B (35.4t)
41 Main ballast tank No 6D (35.4t)
42 Normal lubrication oil tank No 1 (1,457g)
43 Expansion tank (2,993g)
44 Normal fuel oil tank No 6 (15,201g)
45 Normal lubrication oil tank No 2 (924g)
46 Main motor sump (200g)
47 Normal lubrication oil tank No 3 (1,040g)


13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
35 36 37 38 39 40 41 42 43 44 45 46 47
ompartment
Forward engine room
After engine room
Manoeuvring room
After torpedo room

Upholder class cutaway



Upholder class space allocation



Left: The use of two watertight bulkheads dividing the pressure hull space into three main watertight compartments is now unusual. The aft compartment is divided by an acoustic bulkhead, with the propulsion motor room aft of the engine room.

Above: The Upholder class is probably the most sophisticated conventional design available. The cylindrical pressure hull is capped forward and aft by domed bulkheads and constructed of high tensile steel to permit diving depths in excess of 656ft (200m).

All hulls have ballast keels. In the double- and multi-hull configuration the keel is mounted within the outer hull; in the others it is mounted externally. Double- and multi-hull and saddle-tank arrangements have an additional and most valuable advantage in that weapon warheads exploding against the outer plates have a certain amount of their explosive impact absorbed, thus reducing the effect on the pressure hull.

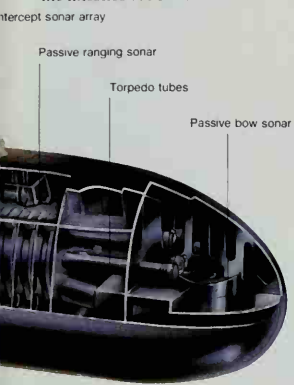
The US Navy has used a series of high-yield (HY) steels for submarine construction, but all classes since the Thresher have been made of HY80. (The number gives the yield stress in lb/sq in; thus, HY80 has a yield stress of 80lb/sq in, or 5.624kg/cm^2). At one time it was planned to build the Los Angeles class boats of HY130, although in the event HY80 was used, and it is now hoped to develop HY130 to an acceptable standard in time for use in the later units of the US Navy's next class of attack submarines.

In other nations there is also much research and development aimed at producing ever stronger materials: titanium, aluminium and even glass have been considered. The Japanese use NS-90 in their Yuushio class, while the French Marel, a new high-tension steel claimed to give a 50 per cent increase in diving depth, is being used in the latest French and Dutch submarines. The USSR has continued to use steel for the majority of its submarines, but at least two classes, Alfa and Mike, are known to be built of titanium. The Alfas are not only the world's fastest submarines, capable of better than 42 knots (75km/h) but also the deepest diving, with estimates of their depth capability varying from 2,000ft (607m) to 3,000ft (914m).

Titanium is a very difficult material to weld, although the Soviets – long world leaders in metallurgy – seem to have overcome the problems. Only six Alfas were built, but their successors of the Mike class now entering service are also constructed of titanium. Titanium has, of course, an invaluable further advantage in that it is non-magnetic and thus undetectable by devices such as airborne MAD and bottom-laid coils. Some years ago the West Germans attempted to achieve similar results by using

Below: The cylindrical form of USS *Ohio* (SSBN 726) is shown as she is rolled out from the giant assembly hall at General Dynamics Electric Boat Division for final completion and testing.

Right: This view of the launch of USS *Phoenix* (SSN 702) includes a revealing glimpse of the missile tubes in USS *Michigan* (SSBN 727) fitting out on the pier. The tubes are located amidships to minimise changes to the trim of the boat as the missiles are fired.



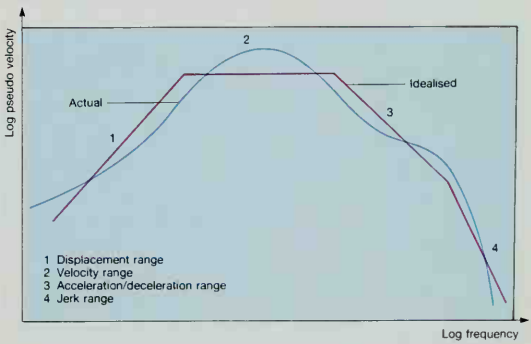
non-magnetic steel for their Type 205, 206, and 207 submarines, which were intended primarily for service in the shallow waters of the Baltic. Early corrosion problems have long since been resolved but the idea has not been extended to larger designs.

The essential body of the submarine is the long, relatively thin, cylindrical pressure hull, stiffened by internal or external ring frames and supported by transverse bulkheads. The pressure hull diameter varies, small changes being achieved by conical sections and large changes by steep torospherical cones, with bulkheads or stiffeners located at the smaller diameter transition point. The two extremities of the pressure hull are closed by domed end-closures, usually hemispherical in shape.

Obviously, the critical factor is the strength and integrity in the hull, which must be enough to enable the submarine to operate at depths specified in the operational requirement. Overall collapse due to insufficiently strong frames in relation to compartment length is a relatively unlikely event, but interframe shell buckling and shell yielding are of greater consequence. The designer endeavours to take all the possibilities of weakness into account, such as variations in material characteristics, residual stresses, deviation in circularity, stress concentrations, etc, in a factor of safety which is normally set between 1.5 and 2.0. This is used in the calculation: collapse depth (design depth) = factor of safety × operational depth. Thus, in a boat with a safety factor of 1.74 (a typical figure) and an operating depth of 300ft (91.4m), collapse depth would be 522ft (159m).

It should be noted that the majority of modern Western deep-diving submarines do not have very strong internal bulkheads, so that penetration of

Shock response spectra



Above: The relationship between velocity and frequency in an underwater attack on a submarine, used in designing shock protection mounts for submarine equipment.

Below: Increasing resources are devoted to trials and research in underwater warfare. Here the former Royal Navy submarine HMS *Porpoise* undergoes conversion to a range target.

Right: A medical orderly on the British nuclear-powered hunter-killer submarine HMS *Trafalgar*. Such boats may be away from contact with land or other ships for months at a time and must be totally self-sufficient.

the pressure hull is likely to he disastrous and escape improbable. Most Soviet submarines, and the West German IKL-designs, do, however, have such bulkheads.

HABITABILITY

An important factor, as submarines require ever more highly trained crews and cruises become longer, is habitability. To a certain extent this problem can be solved by increasing size, but this is undesirable on grounds of expense and detectability, and all navies are aiming for increased automation to enable crews to be

Below: HMS *Trafalgar*'s mess-room, showing the increased space available for social activities aboard modern submarines, easing the strain during long cruises in confined spaces.

Above: The officers' wardroom in HMS *Trafalgar*. Submarine officers of all nations require lengthy training and carry considerable responsibilities, and many Western navies suffer a retention problem.

Left: Even in the large hulls of the latest SSNs – this is USS *La Jolla* (SSN 701) of the Los Angeles class – space is at a premium and the living quarters are located wherever room is available. Some of the crew must share their sleeping space with Mk48 torpedoes.

Right: In *Trafalgar*'s torpedo stowage space every inch is used for weaponry or equipment. Larger submarines merely contain more equipment and it is rare for additional room to be made available for crew comfort.

reduced dramatically. The Swedish Navy's Vastergötland class, for example, with a submerged displacement of 1,125 tons, will have a crew of just 5 officers and 19 men; the Peruvian Dos de Mayo class, similar in size but built in the 1950s, need a crew of 40. Neither type is likely to undertake particularly long cruises, but modern deep sea boats also have lower manpower requirement: the Dutch Walrus class (2,800 tons submerged), for example, will have a crew of 7 officers and 43 men, whereas the US Tang class (2,600 tons submerged) of the 1940s needed 11 officers and 75 men.

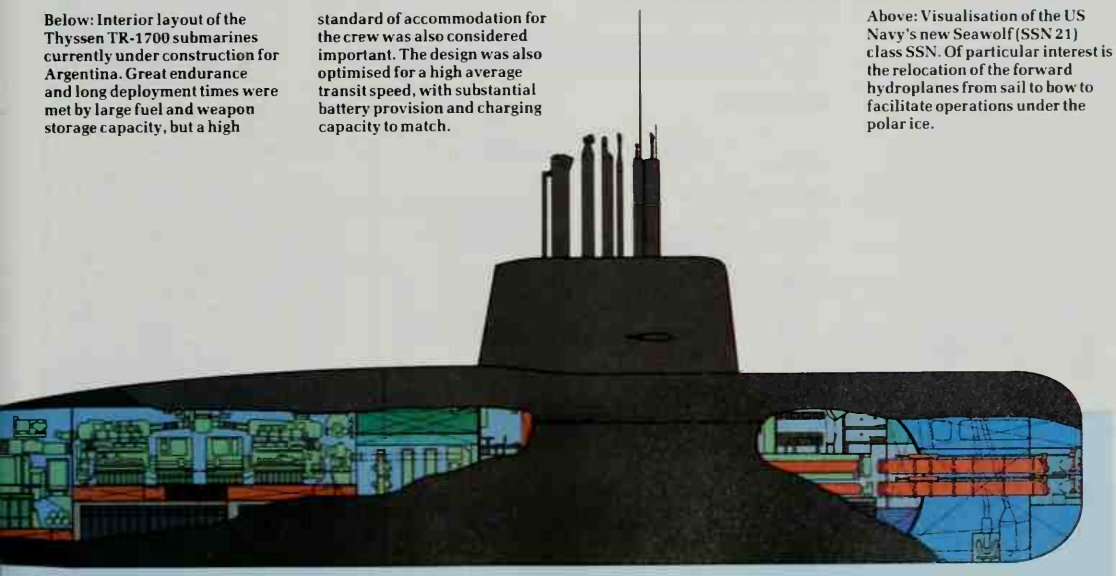
THE FUTURE

Perhaps the overriding factor in future submarine design is that of cost. Even conventional diesel-electric submarines, apart from those designed for restricted waters such as the Baltic, are growing in size and cost, and while many resolutions are made to produce smaller, cheaper designs, they somehow seldom seem to materialise. The major research efforts are now concentrating on making submarines quieter, faster and deeper diving. The emphasis on quietness does not necessarily make a submarine undetectable, but it does make the searcher work much harder, probably to the extent of using active sonar and thus giving himself away.

Possibly the greater potential breakthrough would be to find a propulsion system which would free the non-nuclear submarine from the surface. It seems unlikely that there will be any major advances in battery design, although continual refinement will obviously take place, and while closed-cycle engines and fuel cells both have possibilities a practical system in either field has yet to appear. Nevertheless, there does seem to be a reasonable prospect of viable fuel cells for submarines by the mid-1990s. Nothing is known of Soviet developments in this area, but in view of their huge investments in submarine technology there is no reason to think that they will be behind the West in this field.

Above: Visualisation of the US Navy's new Seawolf (SSN 21) class SSN. Of particular interest is the relocation of the forward hydroplanes from sail to bow to facilitate operations under the polar ice.

Below: Interior layout of the Thyssen TR-1700 submarines currently under construction for Argentina. Great endurance and long deployment times were met by large fuel and weapon storage capacity, but a high standard of accommodation for the crew was also considered important. The design was also optimised for a high average transit speed, with substantial battery provision and charging capacity to match.



Propulsion

The greatest single advance in post-World War II submarine technology is the advent of nuclear propulsion. Nuclear power has released submarines using it from the need for regular forays to the surface to recharge their batteries and has virtually abolished range limitations.

PRESSURISED-WATER REACTORS

All British and American nuclear-powered submarines use pressurized-water reactors (PWRs) in which water acts as both coolant and moderator, a tried and tested technique which has proved exceptionally reliable in service. In such a system water passes round the primary circuit, several times through the nuclear reactor and thence to a steam generator. The cooling water in the primary circuit has to be kept at a high pressure to prevent it boiling and turning to steam, achieved by including a pressurizer in the primary circuit; steam at the top of the pressurizer is used to compensate for changes in coolant volume as the reactor inlet and outlet temperatures vary.

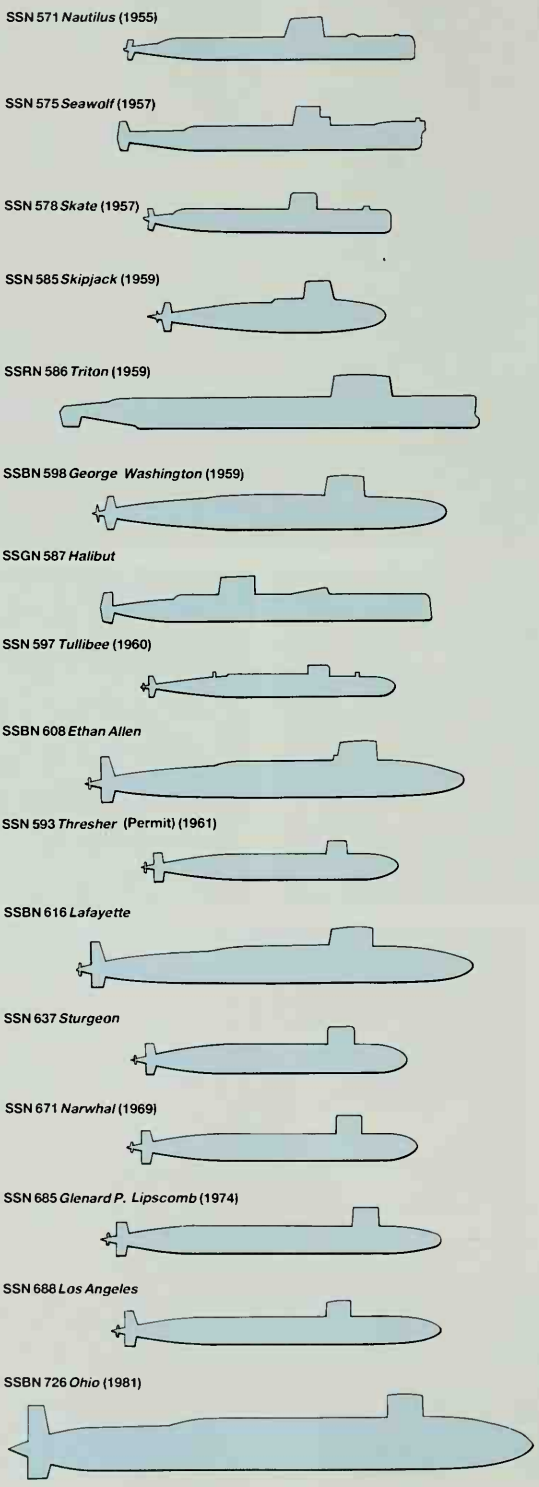
The heat energy is transferred in the steam generator from the water in the primary circuit to unpressurized water in the secondary circuit which then becomes steam and passes through the secondary circuit to the turbine; having driven the turbine it goes into a series of condensers, becoming water once again and returning in liquid form to the steam generator to continue the cycle. PWR condensers use seawater as a heat sink and require a constant throughput, provided either by the forward motion of the submarine or, at slow speeds, by the use of pumps.

The operation of a PWR requires considerable auxiliary power, mainly to operate the circulation pumps in the primary circuit and the electrical heater elements in the pressuriser. The system can be designed to utilise natural circulation resulting from the thermal gradient set up by the nuclear reaction, but at higher power levels the pumps still have to be switched in. Some systems, in an effort to minimise noise and vibration, use several pumps which can be selectively activated according to the power level. Whatever the system, however, all these pumps create noise which is detectable by suitable sensors.

LIQUID METAL-COOLED REACTORS

Various alternative coolants have been tried. The USS *Seawolf* (SSN-575), launched in 1955, was fitted with an S2G liquid sodium-cooled reactor, which gave a much more efficient heat transfer but was very troublesome in service. There were two particular problems: the more intractable was that the sodium had to be kept molten at all times,

US nuclear-powered submarines


SSN 571 *Nautilus* (1955)
SSN 575 *Seawolf* (1957)
SSN 578 *Skate* (1957)
SSN 585 *Skipjack* (1959)
SSRN 586 *Triton* (1959)
SSBN 598 *George Washington* (1959)
SSGN 587 *Halibut*
SSN 597 *Tullibee* (1960)
SSBN 608 *Ethan Allen*
SSN 593 *Thresher* (Permit) (1961)
SSBN 616 *Lafayette*
SSN 637 *Sturgeon*
SSN 671 *Narwhal* (1969)
SSN 685 *Glenard P. Lipscomb* (1974)
SSN 688 *Los Angeles*
SSBN 726 *Ohio* (1981)

Left: Development of US nuclear-powered submarines has been one of logical progression, but there have been aberrations as alternative ideas have been tried. The US Navy's – and the world's – first nuclear-powered boat, *Nautilus*, was powered by an S2W pressurised-water reactor; the alternative S2G liquid-sodium reactor tried in the *Seawolf* was a failure and was replaced by an S2WA reactor.

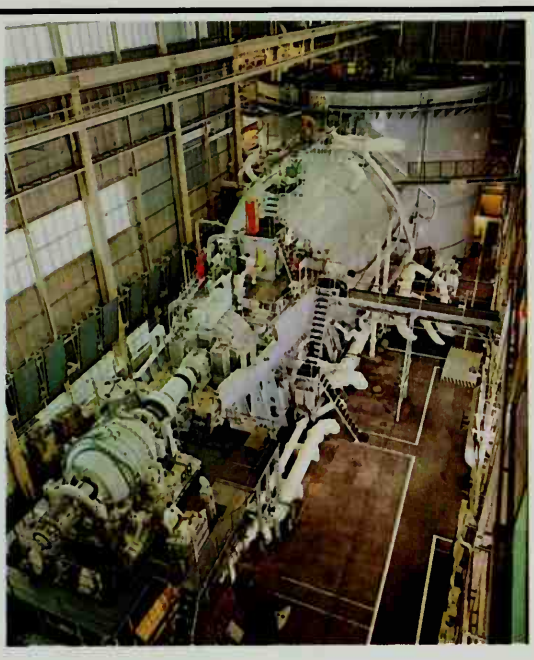
The first production SSNs, the four Skates, were similar to *Nautilus* but slightly smaller. The six boats of the Skipjack class were the first SSNs to have Albacore hulls: indeed, as these comparative profiles clearly show, their hull is the nearest to the ideal of any American SSN. The original leader of the Permit class, *Thresher* (SSN-593), was lost in 1963, but the rest of the class has proved successful in service. The 37-strong Sturgeon class has also proved very successful in service, and led via the turbo-electric driven *Glenard P Lipscomb*, an attempt to produce a truly silent SSN, to the Los Angeles class. The last, with 58 examples already ordered, is probably one of the most expensive but effective defence programmes ever.

The first SSBN type, the George Washington class, was developed quickly by inserting an extra section in a Skipjack hull, and the subsequent Ethan Allen and Lafayette classes have been logical refinements of the design, all carrying 16 ballistic missiles, but the latest Ohio class boats have 24 missiles.

***Tullibee* was the first SSN with a spherical bow sonar dome and midships outward angled torpedo tubes and the last with deck casing. The huge *Triton*, a fleet radar picket, was the only US SSN ever designed to be faster on the surface than submerged, while *Halibut*, the only US nuclear cruise-missile submarine, was armed with five Rugulus Is.**

Right: A submarine pressurized-water reactor (PWR) comprises two circuits: the primary circuit transfers heat from the radioactive core to a water-filled secondary circuit in a heat-exchanger. The PWR's main competitor, the liquid metal reactor, has been dropped by the US Navy, although it is used in at least one Soviet Navy class.

PWRs need auxiliary power to operate the primary circuit circulation pumps, which must be kept running to remove the heat from the pressure vessel; also, the pressurizer needs electrical power to maintain steam. These pumps and generators produce noise, which is one of the main means of detecting nuclear-powered submarines. With proper design natural circulation can be sufficient at low power and the circulation pumps can be switched off, as in the US Narwhal and Ohio designs.



otherwise it solidified and ruined the primary circuit pipes; the second was that the plant was plagued by high-pressure steam leaks. After two years the S2G was replaced by an S2Wa pressurised water-cooled nuclear reactor, virtually identical to that installed in the *Nautilus*. Liquid metal cooling seems to be the only way to obtain smaller, lighter plants, and the Soviet Navy's Alfa class is generally agreed to have a liquid-metal cooled reactor in a fully automatic, unmanned engine room, leading to considerable savings in reactor shielding.

NOISE

A particular problem for nuclear-powered boats is that of

Above: British nuclear submarine propulsion system prototype at the Admiralty Reactor Test Establishment, Dounreay, Scotland. Work on the prototype started in 1957.

noise from gearing and rotating machinery such as pumps which, as described above, must be kept running, especially in PWR systems. In most Western boats machinery is mounted on rafts in an effort to isolate the vibrations from the hull, but turbo-electric drive has been tried in USS *Lipscomb* (SSN-685); the *Lipscomb* is still in service with this system, but it has not been repeated in other boats. Direct drive with twin contra-rotating propellers of different sizes was

Above: The unusually compact nuclear reactor core vessel is installed in a French Navy SSBN (SNLE). The French nuclear submarine programme has been remarkably successful.

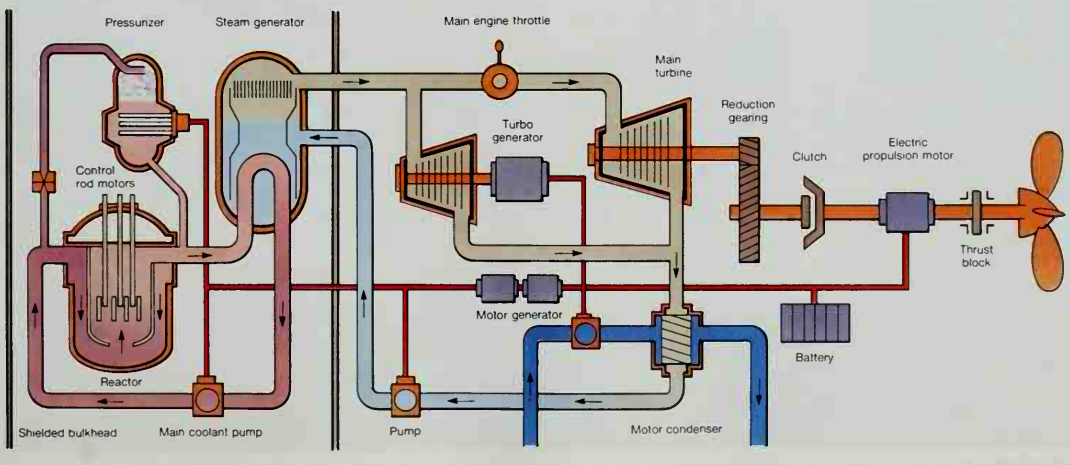
utilised in USS *Jack* (SSN-605), but was unsuccessful and was removed. Free circulation is used in USS *Narwhal* (SSN-671) and has apparently been a success as it is now used in the S8G reactor that powers the Ohio class ballistic missile boats.

DIESEL-ELECTRIC PROPULSION

The diesel-electric submarine is far cheaper to build than a nuclear submarine, is far less complicated to operate and does not invite the political problems associated with nuclear power. However, it has an inherent problem in that it must go to the surface to run its diesels to recharge its batteries, a process which requires about 3.5lb (1.58kg) of oxygen for every 1lb (0.45kg) of fuel oil. In very few submarines are the diesels connected directly to the propeller shafts; rather, the propellers are normally run off the batteries at all times, even on the surface while the diesels recharge the batteries.

Batteries are heavy and space-consuming. Lead-acid batteries are cheap, simple to produce and relatively easy to maintain, while silver-zinc and silver-cadmium batteries are lighter, smaller and more efficient.

Pressurised-water nuclear propulsion system layout



but are much more expensive and need more careful handling. Apart from constant research into new types of battery, much development effort is being put into improving the performance of lead-acid batteries, for example by changing the electrolyte under water to get rid of poisoned electrolyte.

PROPELLERS

The final item in the drive-train is the propeller, which is one of the major causes of noise and one of the most readily identifiable features of an individual submarine. Modern submarine propellers have up to seven blades, usually scythe-shaped, and are designed to be run at very low revolutions. The British Trafalgar class submarines are reported to use pump-jets, in which a ducted, multi-bladed rotor turns against stator vanes, thus virtually eliminating cavitation noise, although rotating noises will probably still exist.

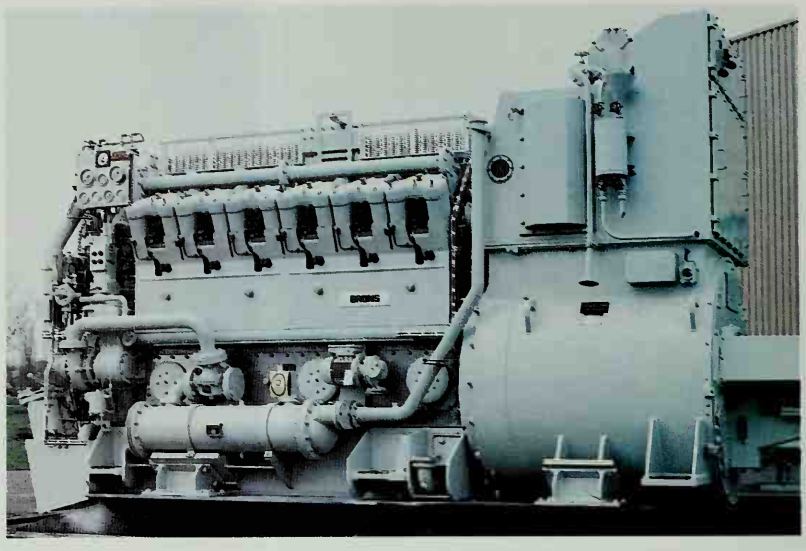
OTHER PROPULSION SYSTEMS

The Soviet Navy is reported to be examining a variety of alternative means of propulsion, and is claimed in *Jane's Fighting Ships 1984-85* to be using both magnetohydrodynamic (MHD) generators and electrodynamic thrust (EMT). The former involves the use of an open tube filled with seawater and surrounded by a ferro-liquid in a sealed sleeve: a pulsating magnetic field causes sympathetic vibrations in the ferro-liquid, setting up a travelling wave which results in the water in the open tube being pumped out at the rear to impart forward thrust to the submarine.

This system, which has similarities with the electro-osmosis process, requires a great deal of electrical power and would probably be capable of moving the submarine only at low speeds. Nevertheless, if a ballistic missile boat was to use normal propeller drive for the relatively rapid transit to and from its patrol area, once there MHD could be very valuable for virtually undetectable low-speed cruise.

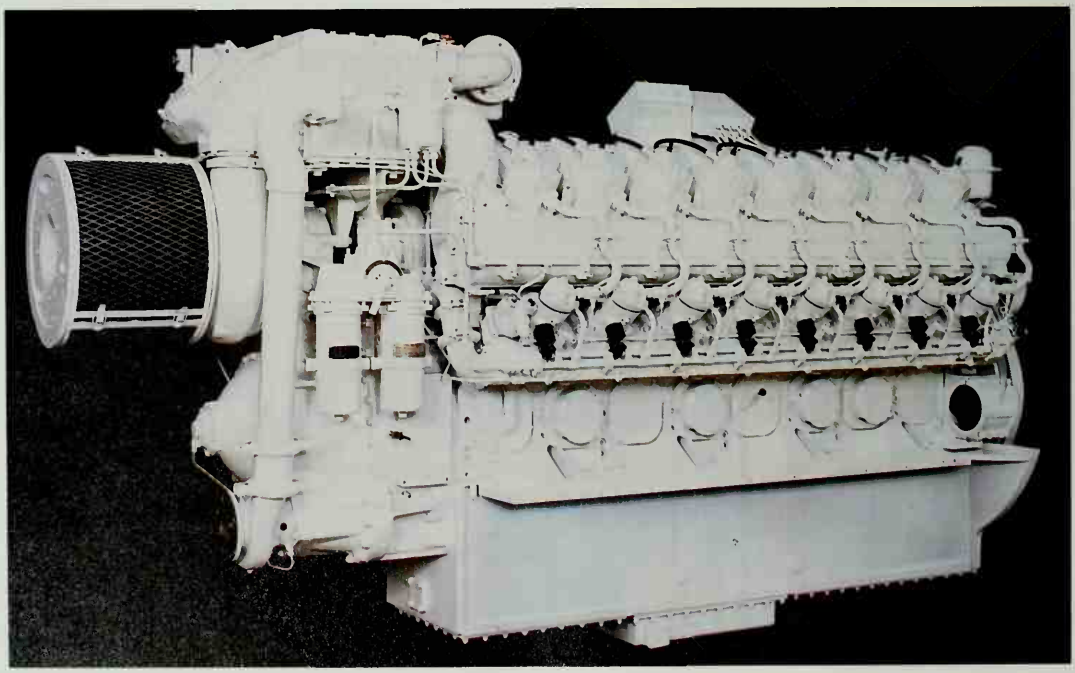
One theory concerning the enormous size of the Soviet Navy's Typhoon class SSBN is that there are two parallel pressure hulls within the outer casing, one of which contains a large nuclear plant to generate the enormous power necessary for MHD propulsion.

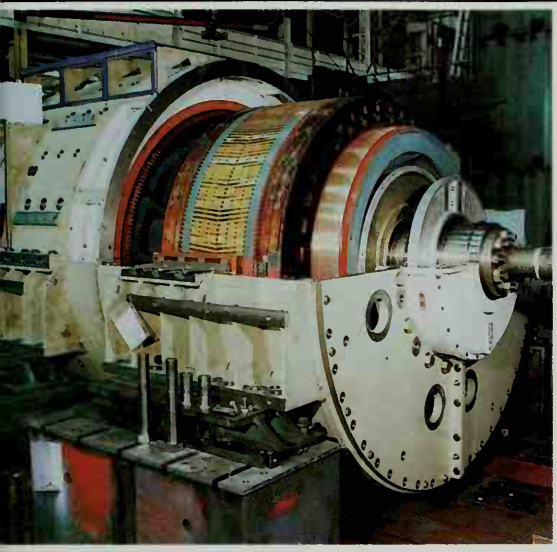
EMT employs a different technique. A line of electro-magnets is set up on the centreline of the vessel and banks of electrodes are mounted on either side: electric current is passed through the electrodes, setting up a magnetic field, and the action



Above: Three of these Brons O-RUB 215x12 1,400kW diesel units are installed in each of the Taiwanese Navy's Seadragon class submarines. At the right is the Holec AC generator with its built-in rectifier and air/water heat exchanger.

Below: Paxman Valenta 16RP 200SZ 16-cylinder diesel (for British Upholders). With a power output of 2,035 hp, this unit has a dry weight of some 8.89 tons (9,000kg). Total weight with the associated electrical generator is 23.4 tons (23,800kg).





Above: The GEC 4MW double-armature non-compensated DC main propulsion motor of the Upholder class. The unit's 85-ton weight and torque loadings are transferred to the submarine's structure by feet extending over its complete footprint.

Below: Stirling-cycle engines burn fuel and oxygen continuously in a combustion chamber, the heat being transferred by conduction to a gas of high thermal conductivity confined in a heater/regenerator/cooling circuit, achieving air-independent power.

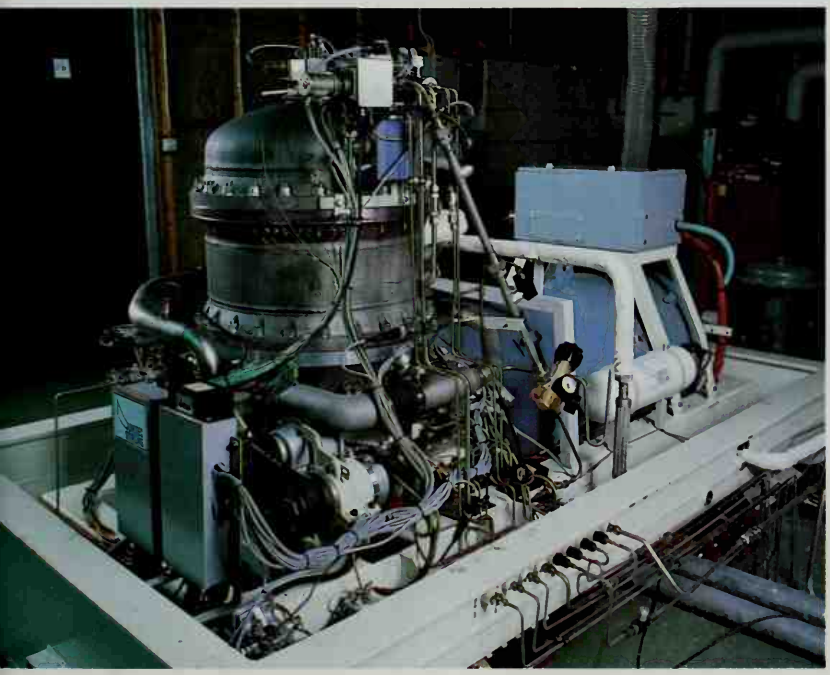
between the two magnetic fields results in forward motion. The Soviet Union and Japan are both reported to be experimenting with this system. Both MHD and EMT produce thrust without the use of a propeller, so there is no cavitation noise, no mechanical noise and less wake turbulence.

Other systems have also been tried. Professor Helmuth Walther proposed a closed-cycle system using high-test hydrogen peroxide (HTP), and four Type XVIIA and three Type XVIIB boats had been completed by the end of World War II. All the latter were scuttled,

Above: The manoevring control console of a Swedish Näcken. The Saab Instruments console allows one man to control the submarine: here the operator is controlling the boat with his right hand while adjusting the speed of the motor with his left.

but two were recovered, *U-1407*, going to the Royal Navy and *U-1406* to the US Navy.

U-1407 was refurbished and, commissioned as HMS *Meteorite*, was used to develop the Walther system in 1947-48, with enough success for the Royal Navy to order two more submarines using the Walther cycle, HMS *Explorer* and *Excalibur*. Of 1,200 tons submerged displacement, these boats were purely experimental; they had no torpedo tubes or radar, mounted only one periscope and had diesel engines to recharge the batteries and to power them on the surface. Using HTP propulsion underwater speeds of 26.5 knots were attained for periods of up to three hours, or 12 knots for 15 hours on one turbine. They proved very hazardous in service, however, to the extent that *Explorer* was known to her crew as HMS Exploder, and they were, in any case, overtaken by the nuclear-powered submarine.



Closed-cycle systems continue to be studied. The Brayton cycle, using inert gases such as argon, helium or xenon as working fluids, was an unsuccessful competitor to power the US Navy's Advanced Lightweight Torpedo, while the Stirling piston engine was under serious consideration for the Royal Swedish Navy's Vastergötland class but was eventually rejected. It should be noted that in any of these systems a fundamental consideration is that if they should give off a gaseous exhaust its disposal is a problem, especially at depth.

Fuel cells have an apparent potential for use in submarines. In such devices two chemicals are combined in the presence of a catalyst, the reaction, which is usually fairly violent, being used for the direct production of electricity. Efficiency is high – up to 70 or 80 per cent in some cases – there are no severe heat dissipation problems, and in many cases, such as lithium/peroxide cells, the product is pure, potable water. No practicable submarine propulsion system has yet been produced using fuel cells, but they are generally considered to be the most likely way forward.

Weapons

After World War II guns were abandoned and for a decade the only weapons available to attack and patrol submarines were torpedoes which had little better performance than those of World War II; indeed, in many cases they were World War II torpedoes. HMS *Conqueror*, for example, sank the Argentinian cruiser *General Belgrano* in 1982 with a Mk 8 torpedo, a model which first went to sea in the late 1930s. The torpedo has had an extraordinary history in recent years, with vast sums being expended by many nations but, until recently, little overall advance in performance or reliability.

Since World War II, however, a whole new range of weapons has given submarines entirely new capabilities – in particular, the ability to carry out nuclear or conventional strikes against targets far inland. The submarine-launched ballistic missile (SLBM) has, for some 20 years, given the submarine the ability to strike at targets anywhere in the world in a counter-value role, and it may now be on the verge of attaining a dangerously destabilising counter-force role as well.

The submarine-launched cruise missile (SLCM) has been around for a similar period and the Soviet Navy has long had specialised boats to carry them. The US Navy also developed some specialised cruise-missile submarines in the late 1940s and 1950s but then decided to produce weapons which could be launched from standard torpedo tubes, the Sub-Harpoon anti-ship missile and the Tomahawk anti-ship (T-ASM) and land attack (T-LAM) missiles. However, after vast expenditure on the Tomahawk programme, it has been realised that the missile will take up too much valuable space in the torpedo rooms and it has been decided to fit them in vertically mounted tubes inside the upper casing between the bow sonar and the forward end of the pressure hull.

The only other submarine-launched anti-ship missile is the French SM39 Exocet, a new version of the very successful missile which achieved such a reputation in the 1982 South Atlantic war. Launched from a standard torpedo tube, the SM 39 has a range of over 312 miles (500km).

BALLISTIC MISSILES

At the end of World War II naval forces were primarily concerned, as they had been for centuries, with combat on the high seas. Heavy guns could be fired at inshore targets up to ranges of about 25 miles (40km) and carrier-based aircraft were capable of strikes even further inland, although seldom more than 100 miles (160km)—but there it ended. By the 1950s, however, the US Navy had developed a land-attack capability with its strike carriers equipped with the North American AJ-1 Savage, which was capable of carrying the Mk 5 atomic bomb whose yield was well in excess of the 20kT of the weapons used in the Nagasaki and Hiroshima attacks. This carrier-based capability, which improved rapidly through the 1950s and 1960s, caused major concern in the Soviet Union and helped spark off its major attack and cruise-missile submarine building programmes.

The next phase in the expansion of navies' traditional roles came with the ballistic missile-armed submarine. Apart from shore bombardment with their relatively small deck gun, submarines had never had a land attack role: the

Above: First launch of Trident I, January 18, 1977. The aerospike deployed on the nose gives the same streamlining effect as a long pointed nose without reducing the vehicle's internal volume.

Below: Test firing of an unidentified Soviet Navy SLBM. The weapon's ratio of diameter to length appears markedly different from that of the Western missiles such as Trident.

Below: Trident I SLBM launched from USS *James Madison* (SSBN 627), one of 12 units of the Lafayette and Franklin classes which have been converted to take Trident I.

Above: Poseidon C-3 SLBM has only been deployed in the Lafayette/Franklin class SSBNs, twelve of which have been converted to take Trident leaving 18 with Poseidon.

Germans had given serious consideration in 1944-45 to methods of transporting V-2 rockets across the Atlantic by submarine to points where they could be launched against the USA, but the war ended before the plan could be implemented. The essence of the idea was sound, however, and both the Soviet and US navies began to pursue the idea in the Cold War era. The first ballistic missile submarines, those of the Soviet Navy's diesel-engined Golf class armed with three fin-mounted SS-N-3 missiles, came into service in 1958, but they were crude systems and the missiles could only be launched from the surface.

Below: Despite renewed interest in nuclear-powered attack submarines by navies such as those of Spain and Canada, nobody is planning to join the extremely expensive SSBN club whose five present members will find that current moves to limit air- and land-based tactical and strategic nuclear weapons will increase the significance of their sea-based deterrent.

Above: Royal Navy-launched Polaris A-3 SLBM. The RN is the only user of this elderly missile, which has been updated by the fitting of new rocket motors and the all-British Chevaline MRV.

SUBMARINE-LAUNCHED BALLISTIC MISSILES (SLBM)

Country	Missle Type	Range		cep		Warhead			Guidance System	IOG	Submarine Type	Number of SSBNs on 1 Jan 87	Number of Missiles per SSBN
		nm	km	nm	m	Type	Number per Missile	Yield (MT)					
USA	Trident C-4	4350	8056	0·25	463	MIRV	8	0·1	Inertial	1979	Ohio	8	24
											Lafayette/Franklin	12	16
	Poseidon C-3	2500	4630	0·25	463	MIRV	14	0·1	Inertial	1971	Lafayette/Franklin	16	16
UK	Polaris A-3	2500	4630	0·5	926	MRV	3	0·2	Inertial	1967	Resolution	4	16
France	MSBS M-20	1860	3445	0·54	1000	Single	1	1	Inertial	1976	Le Redoutable	5	16
	MSBS M-4	2160	4000	0·5	926	MRV	6	0·15	Inertial	1985	L'Inflexible	1	16
USSR	SS-N-6 Mod 2	1300	3000	1	1856	Single	1	1	Inertial	1967	Yankee-I	18	16
											Golf-III*	1	6
	SS-N-8 Mod 2	4800	9100	0·84	1560	Single	1	0·8	Stellar-Inertial	1974	Hotel-III*	1	6
											Delta-I	18	12
											Delta-II	4	16
	SS-N-17	2100	3900	0·75	1410	Single	1	1	Inertial	1977	Yankee-II	1	12
	SS-N-18 Mod 3	3300	6500	0·74	1370	MIRV	7	0·2	Stellar-Inertial	1976	Delta-III	14	16
	SS-N-20	4800	8900	0·35	640	MIRV	9	0·5	Stellar-Inertial	1982	Typhoon	4	20
	SS-N-23	4800	8900	0·35	640	MIRV	10		Stellar-Inertial	1985	Delta-IV	2	16
China	CSS-N-4	2150	3000	n.a.	n.a.	Single	1	2	Inertial	1983	Xia	2	12

* Missiles count towards SALT totals (12) but submarine hulls do not.

After a short-lived consideration of a system involving six solid-fuel Jupiter-S missiles in 8,500-ton submarines, the US Navy settled on the Polaris project. Few weapon systems in history have combined more dramatic technological innovations than this bold concept for a submarine-launched ballistic missile system, which was formulated by Admiral W.F. Rayborn, USN, and a team from Lockheed. The two most fundamental decisions, taken right at the very start, were to use solid propellant and to expel the missiles from vertical launch tubes while the submarine remained submerged, but the project also introduced many other novel technologies: lightweight ablative reentry vehicles, miniaturised inertial guidance, miniaturised nuclear and thermonuclear warheads, cold-gas launch techniques, submarine inertial navigation systems and submarine noise reduction to name but a few. When Polaris reached operational status in November 1960 it changed the nature of strategic warfare and, in particular, of deterrence, and improvement programmes have taken the US Navy from Polaris to Poseidon and now to Trident I (C-4) and Trident II (D-5).

The Soviet Navy ballistic missile programme started with the SS-N-4, a missile so large that it could only just be fitted into a Zulu V class submarine between the keel and the top of the fin. Liquid-fuelled and surface-launched, it was of limited value and was quickly succeeded by the SS-N-5, which, although still mounted in the fin, could at least be launched while the submarine was submerged.

The next Soviet missile, SS-N-6, was small enough for 16 to be installed within the hull of the first Soviet nuclear-powered ballistic missile submarine type – the Yankee class – thus matching the capability of the Western boats for the first time. A further advance was made with the SS-N-8, whose range of 4,800nm (8,890km) far exceeded that of any other SLBM at that time. Then came the SS-N-9 Mod 3, which at last gave the Soviet Navy a MIRV capability.

The SS-N-18, which was the next operational missile, has virtually all the capabilities of the American Trident II, but attained them a decade earlier, and its range of 4,300nm (7,964km) is such that it can threaten the USA from almost any part of any ocean in the world. The latest operational missiles, the SS-N-20 and SS-N-23, each have a range of 4,800nm (8,883km) and are now at sea in the

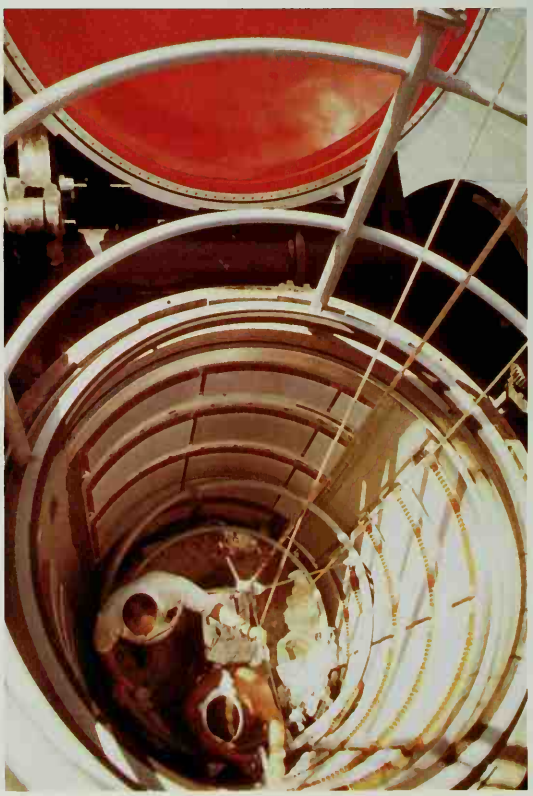
THE USA/USSR SLBM STRATEGIC BALANCE: (a)

Country	Missile	Submarine Type	Number in Fleet	Missiles per SSBN	Total missiles	Re-Entry Vehicles (RV) RVs per missile (c)	Total number of RVs	Effective Megatons (b) Yield per RV (MT) (d)	EMT
USA	Trident C-4	Ohio	8	24	192	8	1536	0·1	486
		Lafayette/ Franklin	12	16	192	8	1536	0·1	486
	Poseidon C-3	Lafayette/ Franklin	16	16	256	10	2560	0·04	512
Total			36		640		5632		1484
USSR	SS-N-6	Yankee-I	18	16	288	1	288	1	288
	SS-N-8	Golf-III	1	6	292	1	292	0·8	261
		Hotel-III	1	6					
		Delta-I	18	12					
		Delta-II	4	16					
	SS-N-17	Yankee-II	1	12	12	1	12	1	12
	SS-N-18	Delta-III	14	16	224	5	1120	0·2	501
	SS-N-20	Typhoon	4	20	80	6	480	0·1	152
	SS-N-23	Delta-IV	2	16	32	10	320	0·5	226
Total			63		928		2512		1440

Notes:
(a) Figures given are for inventory totals of submarines, ie, the total number of submarines in the fleet, as of January 1, 1987; numbers actually available are many fewer. The US Navy has 66 per cent of Ohio SSBNs and 50 per cent of Lafayette/Franklin SSBNs at sea at any one time. The USSR, historically, has an average of just 13 SSBNs at sea.
(b) Effective Megatons (EMT) reflects the damage against soft point targets or area targets such as cities. The effect at a specific point distant from Ground Zero is proportional to the cube-root of the yield, while the area affected is proportional to the square of the distance. Thus:
EMT = (Yield)$^{2/3}$ BUT, where Yield ≥ 1MT then EMT = (Yield)$^{1/2}$
(c) Where missiles carry MIRVs the average load has been taken.
(d) Yield = Raw Yield per RV.

Above: The strategic balance between US and Soviet submarine-launched ballistic missiles was agreed in the SALT-II talks; although never ratified by the US Congress the constraints have been observed by both sides.

Below: Although the scale is different a missile launch tube has to be cleaned in much the same way as a rifle barrel. Here men work on one of the tubes on board USS *James Madison* at the time she was fitted with Polaris A-3.



Above: A US Navy lieutenant mans *Ohio*'s missile compartment control and monitoring panel station. His submarine is armed with 24 Trident I missiles, each with 8 MIRVs – a total of 192 warheads with a combined raw yield of 19,200kT. Trident I is not sufficiently accurate to undertake counter-force strikes.

Typhoon and Delta IV class submarines respectively.

The current ballistic missile systems in all navies are basically similar, differing only in detail and comprising five basic subsystems: the submarine, the navigational system, the fire control system, the missile and the launch system. The submarine is essentially a sea-mobile launch pad providing the missiles with transport and protection from the elements and hostile action up to the moment of launch. As part of this function it provides the other subsystems with electrical, hydraulic and pneumatic power, together with temperature and environmental control and overall systems monitoring.

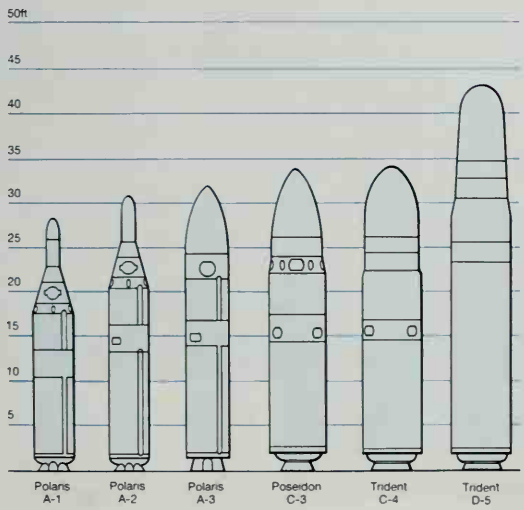
The navigation subsystem is responsible for determining the precise position, velocity and attitude of the submarine, and for transmitting this data in a continuous update to the fire-control subsystem. The principal means of achieving this is the ship's inertial navigation system (SINS), which records every movement of the submarine with reference to a stable platform

Above left: USS *Ohio* (SSBN 726) alongside a wharf while a Trident I missile tube is lowered in by crane. Such operations are carried out quite openly so that orbiting Soviet satellites can observe and record the operation.

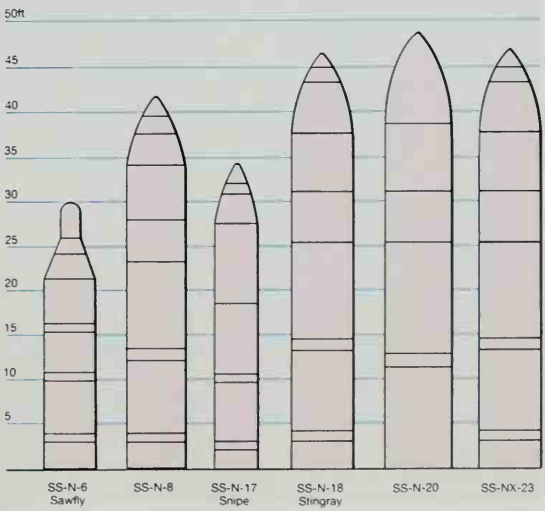
Left: With each missile measuring 44ft (13.4m) in length and 83in (210.8cm) in diameter and weighing nearly 60 tons, the *Ohio* had to be a huge vessel to accommodate 24 Trident IIs.

Below: A comparison of fleet ballistic missiles shows that Soviet missiles are larger than their US counterparts, providing greater payload range but requiring bigger submarines.

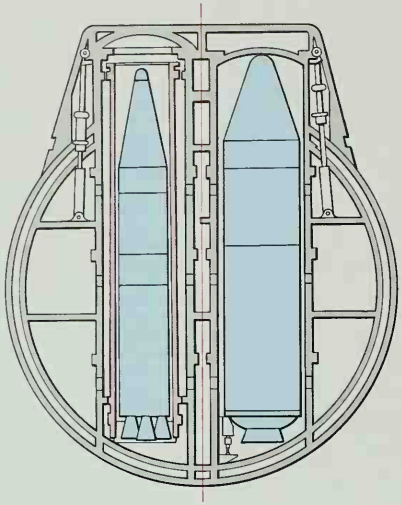
US fleet ballistic missiles



Soviet ballistic missiles



French SLBM installations



Above: The French Navy has developed its own strategic missiles with minimal help from other countries. This diagram compares the current MSBS (Mer-Sol Balistique Stratégique) M-20 with the new M-4 (same length but nearly 30 per cent greater diameter). The M-4 will be retrofitted in four of the five boats built to take M-20; the fifth, *Le Redoubtable*, is too old.

Above: A Missile Technician First Class (Submarines) sitting at the control room console during a simulated missile launch, part of the precommissioning activities aboard USS *Ohio* (SSBN 726). The control panel facing him was one bank of indicators and controls for each of the 24 missiles, but the actual launch must be authorised by two separate officers, each with his own key.

and which can be updated by external inputs such as optical and LORAN observations.

The fire-control subsystem is designed to prepare and fire the submarine's missiles in the shortest possible time. Its essential functions are to set up the missile guidance system inertial platform, to determine true launch bearing, to store and compute target data and to pass data to the missile guidance computer.

The launch subsystem is designed to store, protect and eject the missiles. The missiles are enclosed in capsules stowed inside shock-protected, watertight launch tubes. In some systems high-pressure air is used to eject the missile, while others have a steam generator; either method permits a flameless ejection from the submarine's launch tubes.

The missile is ejected with some force, but approximately 90ft (27.43m) clear of the tube the first-stage motor ignites to propel the missile through the surface, into the atmosphere and up into space. When the first stage has been expended it separates and falls away, and the second-stage motor ignites and propels the missile on its way; a third stage is also fitted to the latest missiles such as the Trident, SS-N-20 and SS-N-23.

During the second and third stages the missile's navigation subsystem is continuously measuring linear accelerations on the basis of its inertial system and altering the missile's trajectory to counteract any unwanted accelerations caused by outside forces. When at the correct

Left: The French MSBS M-4 is a three-stage missile fitted with six TN-70 150kT MRV warheads with a total area coverage (foot-print) of 81x189nm (150x350km) at a range of 2,162nm (4,000km).

Above: The computer suite on board USS *James Madison* (SSBN 627). Early-generation computer technology meant massive data banks were needed to store navigation, test and launch data.

Below: The internal systems of the three-stage Trident II D-5, which makes an interesting comparison with the MSBS M-4 opposite. The MIRVs are mounted on a circular bus in the third stage.

Below: MIRVs from a Trident missile heading toward the US testing area near Kwajalein Island. MIRVs enable one missile to attack a number of separate targets; accuracy is improving.

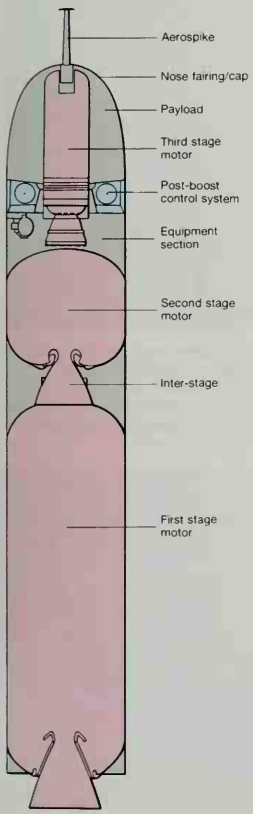
velocity, position and altitude for the assigned targets, the bus carrying the reentry vehicles (RVs) separates from the final stage of the main body of the missile and continues its flight, dropping individual RVs according to predetermined instructions fed to the missile computer just prior to launch. In the terminal phase the warheads reenter the atmosphere at steep angles, the ablative material with which they are coated absorbing the heat of reentry. Penetration aids such as decoys are released at the same time in order to deceive any anti-missile systems.

All SLBMs initially had just one reentry vehicle. However, as the technology developed it became possible to place multiple reentry vehicles (MRVs) on each missile, which were all aimed at the same target but, like shotgun pellets, improved the probability of actually hitting it. The next refinement was multiple independently targetable reentry vehicles (MIRVs) which, as their name implies, could be directed at different targets by being released from the bus at different points. The latest device is the manoeuvrable reentry vehicle (MARV), which contains a device to steer it precisely onto its target, so that its accuracy is independent of the launch accuracy or the precision of the deployment operation in space.

Warhead accuracy is assessed in terms of circular area probable (cep), being the radius in nautical miles of a notional circle centred on the point of aim into which 50 per cent of all warheads launched can be expected to fall. In early SLBM systems the missile navigation system could not be any more accurate than the submarine's SINS, on whose inputs it depended, so early single and multiple RVs were relatively inaccurate and had poor ceps, but the situation improved as both SINS and missile systems developed. Thus, Polaris had a cep of 0.5nm (926m), whereas Poseidon RVs have a cep of 0.3nm (550m), and those of Trident I one of 0.25nm (458m). Soviet RVs were originally even less accurate than those of the USA, but they have caught up: the cep of SS-N-20, for example, is 0.34nm (640m).

As long as the warheads remained fundamentally inaccurate they could only be used in a counter-value role – that is, targeted on cities and other area targets. The imminent advent of MARVs, with accuracies measured in tens of feet, will completely change the situation and there is a strong possibility that SLBMs will,

Trident II D-5



within the next few years, assume a counter-force as opposed to a counter-value role. It is estimated, for example, that the Mk 600 MARV to be fitted to Trident 2 will have a cep of 0.07nm (122m). This is a development with deeply significant implications for the balance of power.

The UGM-93A Trident I missile design requirement emphasised range. The fitting of an aerospike which extends after launch created the same aerodynamic effect as a sharp, slender nose, reducing drag by some 50 per cent, thus enhancing range; with a third-stage motor and improved fuel the missile has a range of 4,350nm (8,056km), compared to Poseidon's 2,500nm (4,630km). To overcome the inherent inaccuracies of the submarine's inertial system the Trident I's Mk 5 navigation system incorporates a stellar sensor which takes a star sight during the post-boost phase, enabling it to correct the missile's trajectory. The eight Mk 4 RVs, whose W-76 warheads each have a 100kT yield, have a reported cep of 0.25nm (457m), which may be reduced to 0.12nm (229m) in future. Their range is 4,230nm (7,833km) with a full eight RVs, or more with a reduced payload.

Trident I was designed to have similar payload and accuracy to

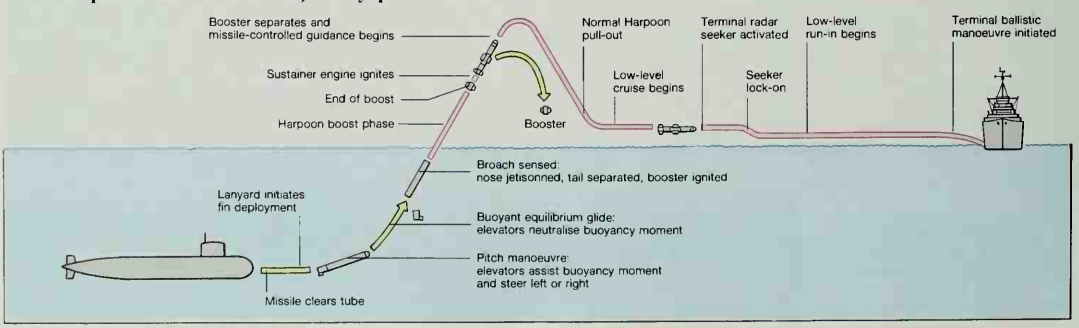
Left: Sub-Harpoon is launched in a buoyant capsule which is jetisonned when the missile broaches the surface. Here the cap is seen being thrown upward prior to the booster ignition that will expel the missile from the tube.

Above: Propelled by its booster the Sub-Harpoon missile accelerates away, with the cap still spinning through the air above it and the jetisonned capsule hidden by the cloud of propellant smoke.

Below: Sub-Harpoon's role is to deliver a 500lb (230kg) penetration/blast warhead over ranges of up to 60nm against surface ship targets. It is propelled by a solid rocket booster and a turbojet sustainer, and after reaching a maximum altitude of 5,000ft (1,500m) it cruises at high subsonic speed and low-level to minimise detection and the effect of countermeasures.

Above: The damage caused to a surface warship target by a Sub-Harpoon. The missile's warhead is constructed of steel and is designed to remain intact after penetration.

Sub-Harpoon launch and trajectory profile


Booster separates and missile-controlled guidance begins
Sustainer engine ignites
End of boost
Harpoon boost phase
Booster
Normal Harpoon pull-out
Low-level cruise begins
Terminal radar seeker activated
Seeker lock-on
Low-level run-in begins
Terminal ballistic manoeuvre initiated
Broach sensed: nose jetisonned, tail separated, booster ignited
Lanyard initiates fin deployment
Buoyant equilibrium glide: elevators neutralise buoyancy moment
Pitch manoeuvre: elevators assist buoyancy moment and steer left or right
Missile clears tube

Above: A Tomahawk cruise missile launched from a submerged submarine off California approaches its target on San Clemente Island more than 400 miles (640km) away.

Below: Moments later the 1,000lb (450kg) warhead has detonated, totally destroying the aircraft target. Such a land-attack capability is new for submarines.

Below: The French equivalent of Sub-Harpoon is the SM 39 version of the successful Exocet anti-ship missile. This picture shows the moment at which the booster rocket separates from the missile.

Right: This US DoD official drawing shows a Soviet Yankee class which has been converted from its previous role as an SSBN to test the new SS-NX-24 submarine-launched cruise missile.

those of Poseidon but much greater range to allow the use of larger patrol areas. Trident II, however, is designed for greater accuracy; the resulting D-5 missile is longer – 45.8ft (13.96m) compared to 34.08ft (10.4m) – but only marginally greater in diameter, and is capable of carrying 14 RVs, though the SALT II agreement imposes a limit of ten.

The Mk 5 RV has a yield of 475kT and a cep of 0.19nm (122m), but the Mk 600 MARV may be carried in due course. The Mark 5 RV is reportedly designed to take different warheads tailored to the target assignment. Trident II is scheduled to equip 20 Ohio class SSBNs and four new British SSBNs. Each US boat will have 20 missiles, each with 10 RVs, for a total war load of 200 RVs, but the British government has stated that its Trident IIs will carry no more warheads in total than would have been carried by Trident I, which implies longer ranges and much greater flexibility in the Royal Navy's choice of patrol areas.

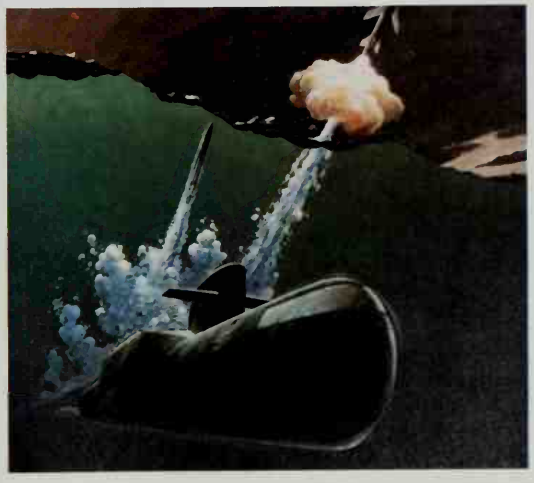
The Soviet Navy has recently introduced two new SLBMs, the SS-N-20 on the Typhoon class and the SS-N-23 on the Delta IV. The former is a three-stage solid-fuel missile with a design range of some 4,800nm (8,890km) carrying between six and nine RVs, and on October 21, 1982, the first Typhoon class SSBN conducted a simultaneous launch of four SS-N-20s; cep is 0.35nm (640m). Little is known of SS-N-23 except that, somewhat surprisingly, it is liquid-fuelled, and that it has greater throw-weight and accuracy than the SS-N-18 fitted to the Delta IIIs. It carries up to seven MIRVs.

The other nations currently possessing submarine-launched ballistic missile systems are the United Kingdom, France and China. The current British missile is the Polaris A-3, which was remotored in the early 1980s, and given a brand new front end of entirely UK origin and the designation Chevaline. Each missile is reported to carry six MRVs with a nominal yield of 40kT each, plus decoys. The older French SSBNs carry the M-20 missile, but the latest boats to join the fleet carry the new M-4 missile with six 150kT MIRVs. The Chinese SSBNs, of which two are believed to be in service with at least two more building, are armed with the two-stage solid propellant CSS-N-3. The first submerged launch of this missile took place on October 12, 1982, from the Chinese Golf class trials submarine, and its range is believed to be of the order of 1,500nm (2,795km). No other nations are known to be contemplating joining this very exclusive and extremely expensive club.

CRUISE MISSILES

The original naval strategic missile was the US Navy's Regulus, a cruise missile designed for use by both surface ships and submarines which was deployed with the US fleet in the 1950s and 1960s before being superseded by Polaris. The Soviet Navy has had tactical cruise missiles for many years, but in the 1970s the US Navy began development of a strategic SLCM which had the attraction of not being covered by existing arms limitation agreements: the BGM-109 Tomahawk is now in wide service with the US fleet and a similar missile, designated SS-N-21 by the US, is in service with the Soviet Navy.

Tomahawk was designed from the start to be fired by either surface ships from armoured box launchers or from standard submarines torpedo tubes. This target was achieved and Tomahawk is now being deployed in numerous surface warships as well as most Los Angeles class attack submarines. The earlier boats use Tomahawk in the torpedo tube mode with 12 missiles per boat, but a reappraisal by the US Navy concluded that this reduces their torpedo capacity. (Considering the vast expense that was incurred in ensuring that



Tomahawk would fit a standard torpedo tube, it seems extraordinary that nobody thought of this earlier.) As a result it has now been decided that SSN-721 and subsequent boats will have 15 vertical Tomahawk launch tubes in the bow casing between the outer and inner hulls, an installation which can be achieved without detriment to other on-board systems.

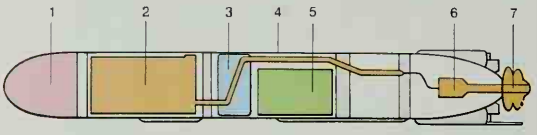
When fired from a submarine torpedo tube the Tomahawk missile is expelled hydraulically and a lanyard 33ft (10m) long runs taut then fires a rocket boost motor which burns for about seven seconds to drive the missile upwards in a 50° climb, through the surface and into the atmosphere. Once clear of the water the wings and tail extend and the gas turbine is started up; the missile then noses over to avoid radar detection and starts its cruise toward the target, travelling at very low level at about Mach 0.7 (550mph). The land attack version (T-LAM) is fitted with the Tercom-Aided Inertial Navigation System (TAINS) and when land is reached the Terrain Comparison (TERCOM) system starts to compare the ground beneath the missile with data stored on magnetic tape, which has been fed in from the submarine immediately prior to launch. TERCOM does not operate continuously, as that would alert the defences and attract countermeasures, but switches on when crossing the coast and at other selected reference points to update the inertial system, which remains in command throughout. The missile can be programmed to approach the target from any direction to confuse defences and its accuracy is incredible, a cep of approximately 33 yards (30m). The missile is dual-capable – that is, it can be fitted with either a high-explosive or a nuclear warhead, the nuclear warhead being the W-80, which has a 200-250kT yield. Range is 1,367 miles (2,200km).

There is also a ship-attack version (T-ASM). The main problem with T-ASM is that to exploit its capabilities fully it needs external target information; a system known as Outlaw Shark is being deployed to provide this, but two-way communication with submarines is notoriously difficult. T-ASM has a range of 250 miles (400km).

The UGM-84 Sub-Harpoon is an all-weather anti-ship cruise missile; the standard Harpoon missile has a diameter of 13.5in (0.343m), but the submarine version is fitted with a shroud to enable it to fit a standard 21in torpedo tube. As with Tomahawk a rocket booster drives the missile up through the water until, once airborne, the turbojet starts up. The warhead weighs 500lb (227kg) and the missile can attack ships up to 60 miles (97km) away. Sub-Harpoon is being purchased by various Western Navies.

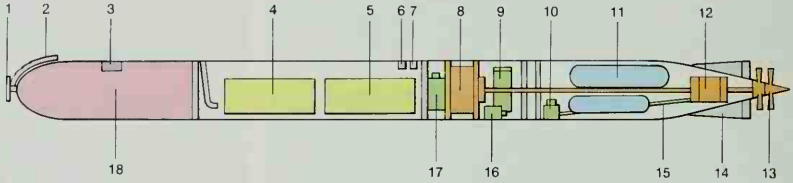
Right: Many Western navies are equipped with the obsolescent Mk 37 torpedo but find modern replacements too expensive. Honeywell markets an upgrade kit to produce the NT 37E (New Technology Mk 37). The improvements are designed to make existing torpedoes 40 per cent faster and more than double their range, as well as improving reliability and tactical flexibility. Key to performance gains is the replacement of the electric drive by an Otto-fuel propulsion system.

Honeywell NT 37E modernisation kit



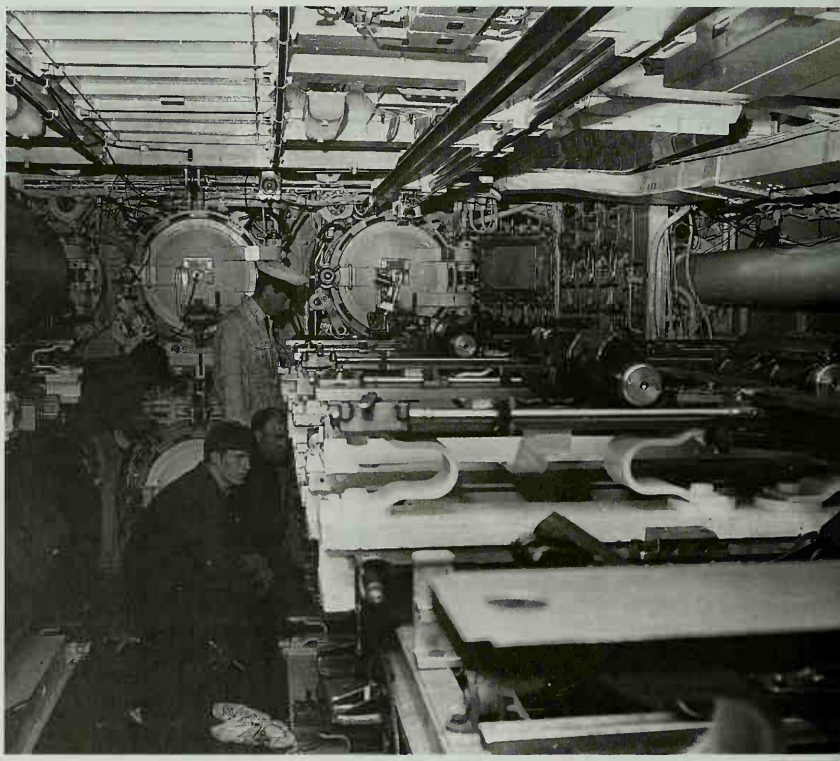
1 Self-noise reducing nose assembly
2 Fuel cell
3 Solid-state acoustic panel
4 Fuel lines
5 Software-programmable guidance and control system
6 Thermo-chemical Otto-fuel rotary piston cam engine
7 Contra-rotating propellers

Late-1940s electric torpedo



Above: A 21in submarine-launched, electric-powered torpedo, circa 1946. With a length of 18ft 11in (5.76m) and a weight of some 3,100lb (1,406kg), it had a speed of 30 knots and a range of 5,000 yards (4,572m).

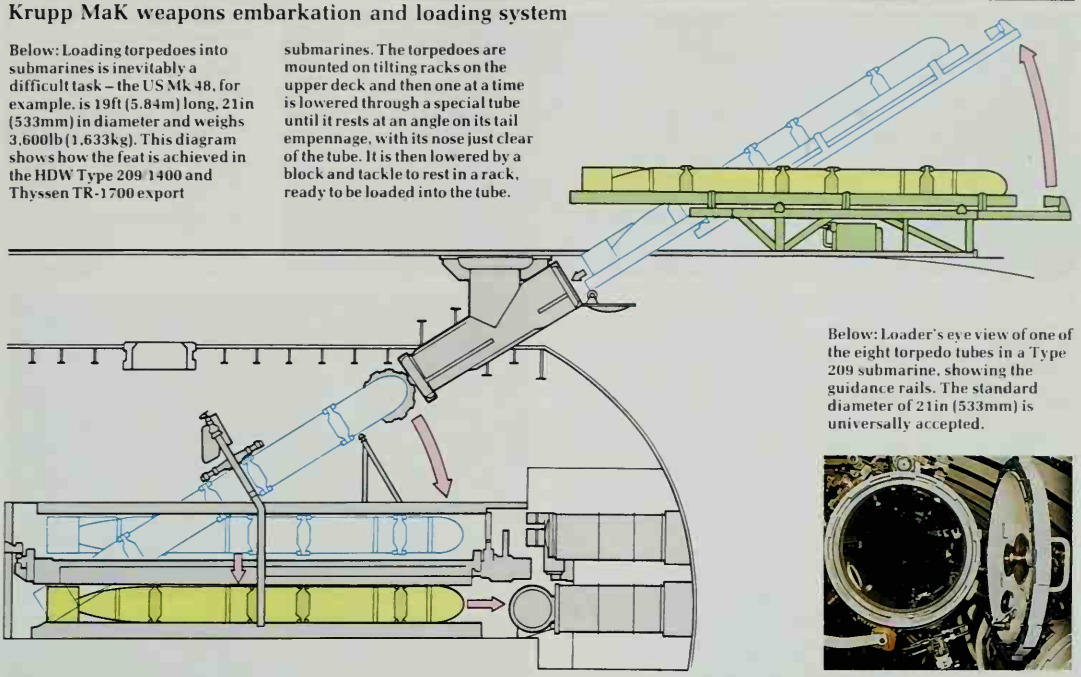
1 Whisker
2 Net cutter
3 Detonator and firing pistol
4 Fore battery
5 After battery
6 Starting switch
7 Heating plug
8 Electric motor
9 Depth control gear
10 Hydrostatic valve
11 Compressed air bottle for driving gyro
12 Gearbox
13 Twin contra-rotating two-bladed propellers
14 Fin and rudder
15 Shafts to rudders
16 Gyro
17 Range-setting group
18 Warhead



Above: The torpedo stowage compartment on board the Royal Navy Polaris submarine *Resolution*. An SSBN would be most unlikely to use its torpedoes except in the direct emergency; it depends on stealth for survival. This picture fails to reveal the type of torpedo in use, though it is probably the old Mk 8. The Royal Navy, like many other navies, has spent vast sums on torpedo development since World War II, but only in the mid-1980s did these programmes start to bear fruit.

Krupp MaK weapons embarkation and loading system

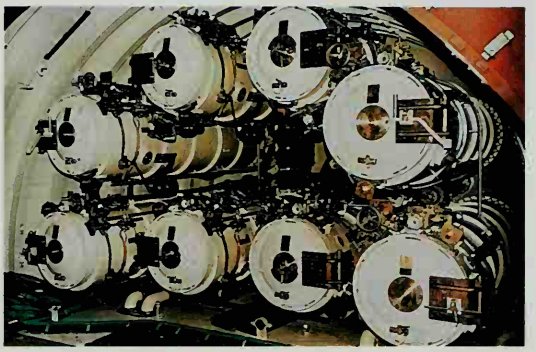
Below: Loading torpedoes into submarines is inevitably a difficult task – the US Mk 48, for example, is 19ft (5.84m) long, 21in (533mm) in diameter and weighs 3,600lb (1,633kg). This diagram shows how the feat is achieved in the HDW Type 209/1400 and Thyssen TR-1700 export submarines. The torpedoes are mounted on tilting racks on the upper deck and then one at a time is lowered through a special tube until it rests at an angle on its tail empennage, with its nose just clear of the tube. It is then lowered by a block and tackle to rest in a rack, ready to be loaded into the tube.



Below: Loader's eye view of one of the eight torpedo tubes in a Type 209 submarine, showing the guidance rails. The standard diameter of 21in (533mm) is universally accepted.

Above: A mine is loaded into a French Daphné class submarine. Although smaller than torpedoes these are still awkward to load – this French mine weighs around 1,875lb (850kg).

Below: RN submariner working on a Sub-Harpoon missile canister. This missile is fired from a standard 21in (533mm) torpedo tube and for every missile carried the torpedo load is reduced by one.



Above: The standard eight-tube assembly installed in HDW Type 209 export submarines. This is the heaviest battery of tubes in any submarines: most contemporary types have six or fewer tubes.

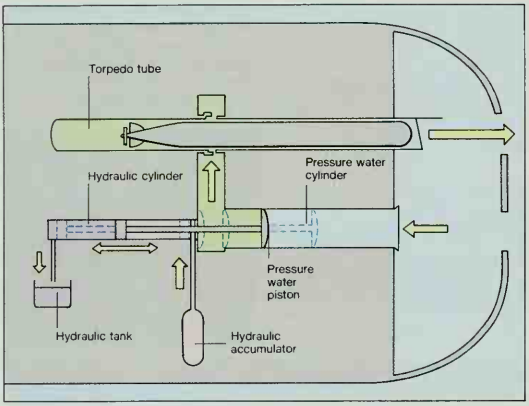
including those of the UK and Japan.

The Soviet Navy is producing similar systems. The smallest is the SS-N-21 which, like Tomahawk, has been designed to be fired from standard torpedo tubes. Possible applications for this missile include recent attack submarines such as those of the Victor III, Akula, Mike and Sierra classes, as well as the former Yankee class attack conversions of ballistic missile boats. According to data released so far, the SS-N-21 is a little larger than Tomahawk, with a range of the order of 1,620nm (3,000km).

However, the second Soviet naval SLCM, SS-NX-24, is much larger, with a length of around 40ft (12m) and a diameter of 4.1ft (1.25m); the highly swept wings have a span of 19.5ft (5.94m). Another Yankee class boat has been converted to be the trials platform for this new missile, which will probably become

Left and below: The decommissioned Royal Navy Type 12 frigate *Berwick* was the target in an October 1986 'Sinkex' to test the Marconi Tigerfish Mod 2 wire-guided torpedo. The torpedo was launched at long range from nuclear-powered attack submarine HMS *Tireless* in Sea State 5 and broke the back of the target, which then became a total loss. Tigerfish entered service in 1979 but was plagued by unreliability problems; these now appear to have been resolved.

Krupp MaK TR-1700 torpedo discharge system



Above: The new Krupp MaK hydraulic system for ejecting torpedoes from their tubes. Such a technique is needed both for safety reasons with the new monopropellant fuels, and to enable torpedoes to be launched against the high water flow encountered when a submarine is travelling at high underwater speeds. Using compressed air would make life uncomfortable for the crew if a salvo of torpedoes were launched in quick succession, as the air would have to be vented into the submarine.

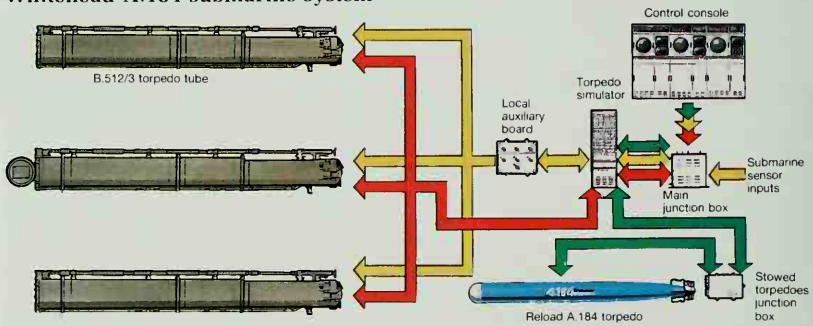
operational in 1987-88. Both systems are likely to be as accurate as their US counterparts, and presumably could also have either nuclear or conventional warheads.

TORPEDOES

Torpedoes have been the subject of some extremely expensive – and often abortive – development programmes. Current models have top speeds which are now being equalled or even surpassed by those of their quarry; the US Mk 46, for example, has a speed of 40 knots, exactly that of the Soviet Alfa class, so a stern chase is out of the question. The problem of lack of speed and range in torpedoes has been partly answered for surface ships by the use of helicopters and stand-off delivery systems such as Asroc and Ikara and, in the case of submarines, by Subroc, but there is still a need for a much faster torpedo. In the US this has led to the Advanced Capability (ADCAP) programme for the Mk 48 torpedo, which will raise its speed to 55 knots (63mph); the British Tigerfish is reported to be capable of a similar speed.

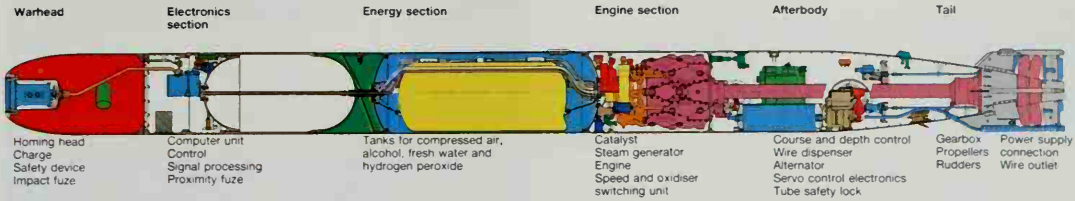
Most modern torpedoes have complicated guidance systems, typically including an

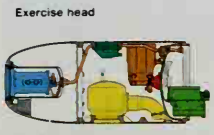
Whitehead A.184 submarine system



Above: The components of the Whitehead A.184 submarine torpedo system. The control console and main junction box are located in the control room, with the other units in the torpedo room. The optional torpedo simulator is used for attack team training and to check that the system is functioning properly. Right: The A.184 is 19ft 8in (6m) long and weighs 2,790lb (1,265kg). It combines wire guidance and acoustic homing and delivers a 550lb (250kg) warhead against surface or submarine targets.

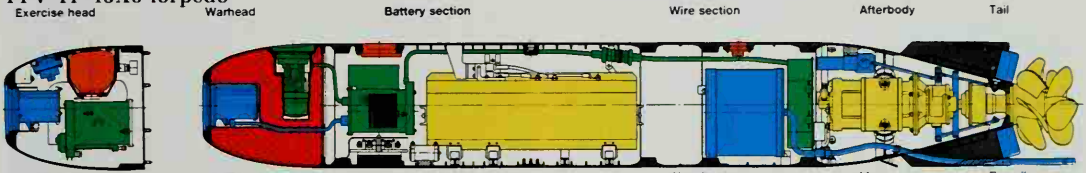
FFV TP 617 torpedo





Above: The Swedish FFV Ordnance TP 617 21in (533mm) torpedo is an export version of the Swedish Navy's Type 613 long-range torpedo. Combining wire guidance and acoustic homing it weighs 4,078lb (1,850kg) and is 22ft 11½in (7m) in length. Designed for use against surface targets by surface ships and submarines, it can also be launched from shore-based submerged torpedo tubes by coastal defence units and has a thermal propulsion system which uses hydrogen peroxide alcohol and water as propellants. The TP 617 system is designed around a programmable digital computer which controls the homing system, communications between torpedo and launch vessel and the torpedo navigation system. The use of wire guidance enables the launch vessel to transmit orders to the torpedo, controlling its speed, depth, course and target data, while the torpedo is able to report its position, speed, course and depth, homing system parameters and target noise. Should communications be disrupted the computer automatically calculates the target's expected position and then guides the torpedo to the predicted point.

FFV TP 43X0 torpedo



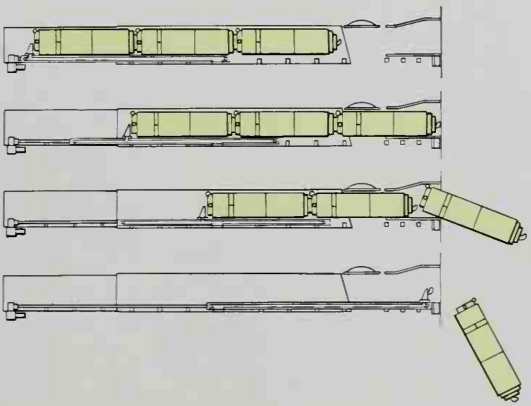
Above: The TP 43XO is intended for use by surface ships, submarines and helicopters against surface or submarine targets. Designed around a multi-processor computer system, it features a homing system optimised for use against very quiet submarines in shallow water and combines wire guidance with passive acoustic homing to give a high hit probability, even at long ranges. Speed, depth, course and target data commands can all be transmitted via the guidance wire, while the torpedo reports its position, speed, course, depth, homing system parameters and target noise all of which are stored in a computer.

active passive sonar transducer working initially in the passive mode and changing to active automatically once the target indicates that it has become aware of the attack. Guidance wires linking the torpedo to the launching submarine are used to pass commands to the torpedo and sonar information back to the submarine's system.

Warhead design is also becoming more important as submarine hulls become ever stronger, the most difficult target being the enormous double-hulled Soviet Typhoon class SSBN. Some form of directed-energy (hollow-charge) warhead is necessary in such circumstances.

In general terms, however, the capabilities of current torpedoes lag behind those of the sonars that support them: they are slow, lacking in range and very noisy. Reports from the South Atlantic War of 1982, for example, abound with stories of both the Royal Navy and the Argentinian Navy suffering from malfunctioning torpedoes. The USSR and some other nations are experimenting with electric motors, but so far these have proved quiet but slow and lacking in range. Increases in either can only be obtained by more battery power, which means bigger torpedoes or smaller warheads. Torpedo sonar, too, needs to be improved and the US Defense Advanced Research Projects Agency is working on this, possibly heading towards a torpedo with on-board signal processing, coupled with an interactive fibre optic link with the parent submarine.

Krupp MaK mine-laying system



Above: The Krupp MaK mine-laying system employed with the torpedo tubes of the TR-1700 is typical of a number of such systems in use: three mines are carried in each tube, and a continuous belt on its mounting is pushed forward by a hydraulically operated piston, revolving as it moves, to expel each mine in turn. The forward part of the tube is designed to allow the mine to assume the correct angle prior to its final expulsion. Submarine-laid antisubmarine mines represent a major threat, particularly when laid in choke points or along known submarine routes. A submarine is unlikely to carry a complete load of mines but might use two tubes for this.

MINES

Mines are very effective antisubmarine weapons. Modern antisubmarine mines operate on one or more of a submarine's acoustic, magnetic or electrical signatures, and can be difficult to counter. Particularly effective is the US Captor (enCAPsulated TORpedo), a bottom-lying mine that fires a torpedo.

Most modern submarines can carry and deliver mines, launching them from their torpedo tubes. This results in precise, clandestine placement of the mines, but they can only be carried at the expense of the normal load of torpedoes. The West German Type 206 submarine, however, has an external mine-belt which enables it to carry 24 mines in addition to its torpedoes.

Sensors

Once submerged, the submarine is totally dependent upon its sensors, the most important of which is sonar. Most submarines have a large sonar mounted in the bow and many, such as American SSNs and SSBNs, are also fitted with conformal arrays. Hydrophones are also carried, usually with arrays near the bow, amidships and near the stern to give all-round coverage. One important submarine sensor is that for listening to its own noises: most navies use a surface ship to inspect their submarines as they leave harbour for noise emissions, but it is vital to continue such monitoring throughout the patrol to ensure that any new noise is detected and removed; otherwise it will act as a beacon for ASW forces.

Just as important as the sensors themselves is the ability to assimilate and process their outputs, and in this field modern technology is making a major contribution. Not only are modern processurs able to handle vast amounts of information but they are much smaller and easier to use.

ACTIVE SONAR

Active sonar devices transmit acoustic pulses in the andio frequency band (approximately 5-20kHz) with pulse rates variable between 12.5 and 700 milliseconds. Snch variations in frequency and pulse repetition rates are necessary to enable adjustments to be made to suit the prevailing oceanic conditions. Active sonars are used in submarines, surface vessels and air-deployed sonobuoys. They are also fitted in torpedoes, using somewhat higher frequencies – typically 20-35kHz – where shorter range is offset by improved spatial resolution.

One characteristic of all underwater transducers is self-noise, which is generated by the relative movement between the acoustic transmitter-receiver and the water surrounding it. A further complication is that transmission power is limited by the cavitiation effect of gaseous bubbles forming on the emitting surface. But the greatest difficulty for sonar is the complex variation in the prevailing conditions of the ocean described above, and to maximise a submarine's sonar capabilities it is frequently necessary to carry a variety of sonar sets, optimised for different regimes. And the major drawback of active sonar has always been that, by its very nature, an active system reveals its presence, enabling the target to detect it and take evasive action.

Active sonar systems comprise large numbers of transducers mounted in arrays. Cylindrical arrays are normally used in the bows of submarines, with beams formed electronically to give directional resolution, while Doppler shift in the return signal gives moving target indication, though a very slow moving target with a low Doppler in a noisy or high reverberation environment, such as a patrolling SSBN, is notoriously difficult to detect, even for another submarine.

The most effective current submarine active sonars are the US Navy's BQQ-5 installed in the Los Angeles class boats and the British Type 2020 now being installed in the Trafalgar class. The BQQ-5 has a bow-mounted spherical array which, using the Submarine Active Detection System (SADS) upgrade, is integrated with other onboard systems such as the Mine Detection and Avoidance Sonar (MIDAS), under-ice systems and the forward-mounted conformal array.

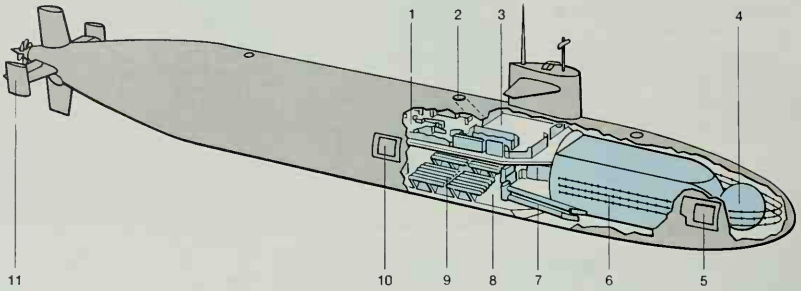
As with surface warships' sonars, further developments in submarine active sonar centre on maximising its excellent detection capabilities while trying to reduce its characteristic and revealing signature. Spread-spectrum transmission, in which the signal energy is spread over a wide range of frequencies in a pattern known only to the transmitter and receiver, may enable the signal to be lost in the general oceanic noise. It also increases the probability of overcoming fluctnations in the acoustic path inherent in the oceanic environment.

Parametric sonar depends on the mixing of two high frequencies to produce a different frequency (higher minus lower) which is then selected for transmission. Careful selection of the original frequencies will generate a suitable sonar signal (100-1,000Hz) with a narrow band-width, giving much better spatial resolution than can be obtained using a normal low-frequency beam. Although used in navigation, parametric sonar has been limited by problems over electronic scanning and in reducing transducers to a reasonable size.

PASSIVE SONAR

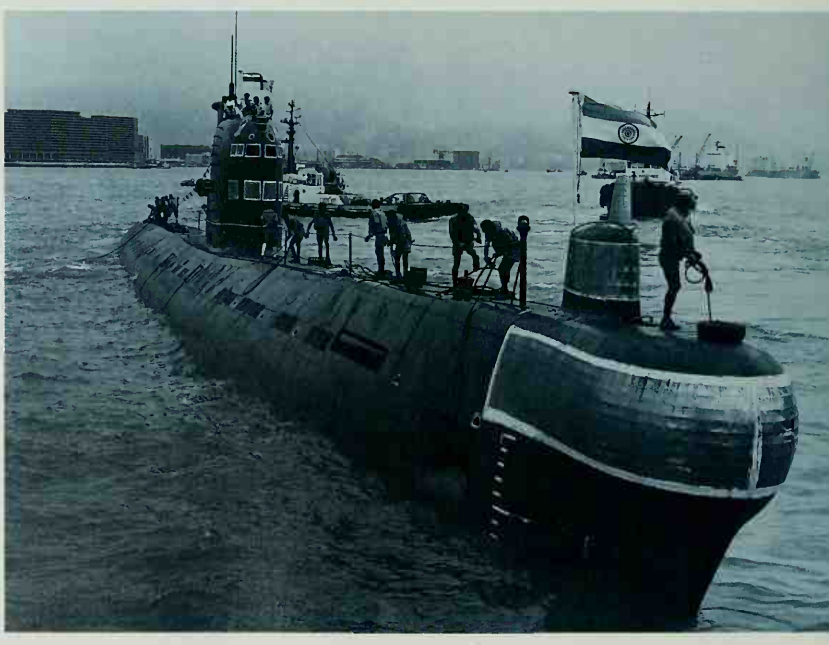
Of much greater importance to submarines is passive sonar, which involves no transmissions and so avoids giving away the submarine's position. The detector is the hydrophone, a very sensitive listening device optimised for submarine noises which can be assembled in a variety of arrays according to the particnlar task, although the only substantial

Los Angeles class combat systems

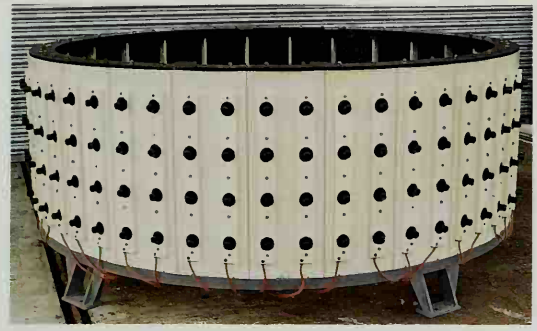


Above: The three hydrophone arrays on each side are for the passive underwater fire control system; not shown is the BQR-15 towed array.

1 Sonar control centre
2 Torpedo hatch
3 Attack control centre
4 BQQ-5 spherical sonar transducer
5 Bow hydrophone array
6 Conformal sonar
7 Torpedo tubes
8 Weapon control centre
9 Torpedo stowage
10 Midships hydrophone array
11 Aft hydrophone array

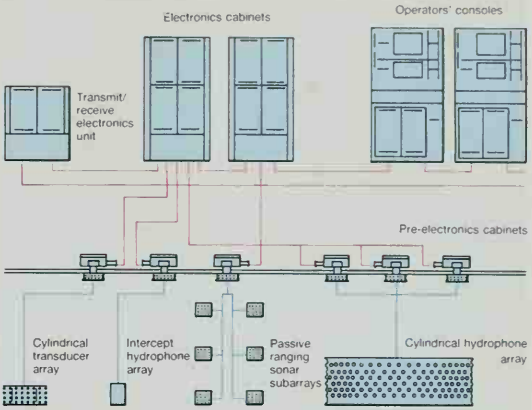


Below: A Soviet-built Foxtrot class submarine of the Indian Navy shows the sound-transparent, unpainted windows for the passive Herkules (bow) and active Feniks sonars.



Above: This cylindrical sonar bow array of 196 transducers is part of the Plessey Triton system. The array is stationary, the sonar beam steered electronically.

Krupp Atlas Elektronik CSU 83 sonar system



Right: Typical installation for small subs—passive panoramic, ranging and intercept sonars; active operating sonar; data handling system; and operator displays.

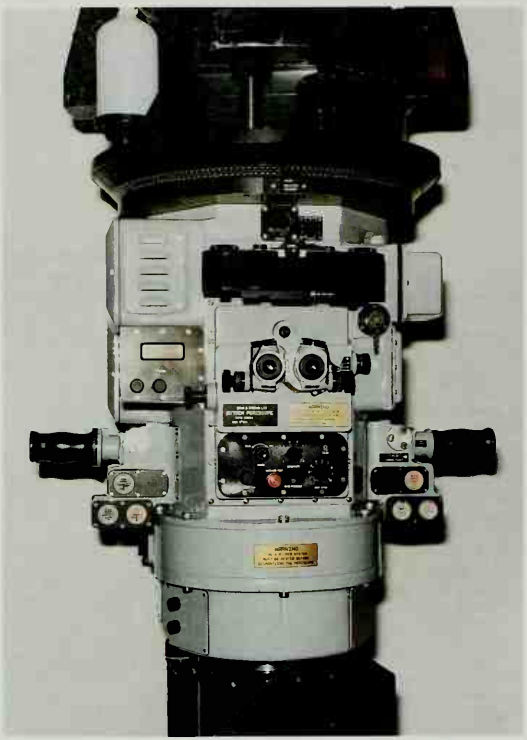
differences lie in the signal processing techniques.

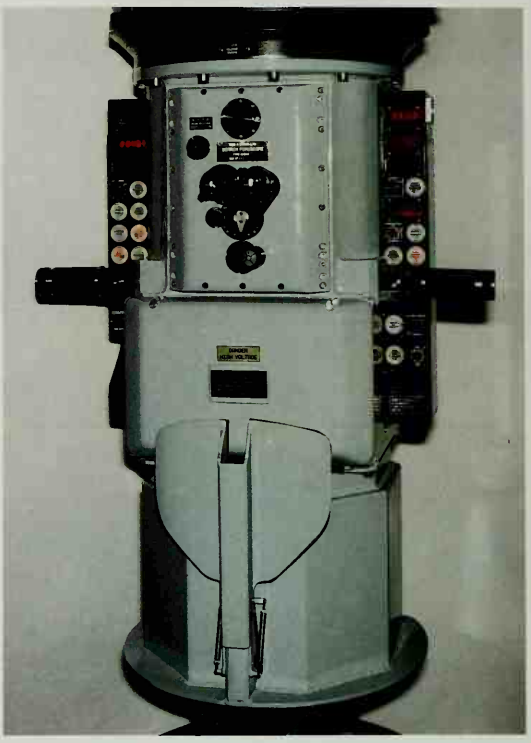
Narrow-band processing is an extremely sophisticated technique which requires spectrum analysers and great computer power to produce its information, although the current revolution in microprocessors is easing this problem. The USA is clearly ahead of the world, and especially of the USSR, in this area, which is of crucial importance in detecting and analysing slow-moving targets.

Broad-band processing looks at the full spectrum of incoming signals and separates constant noises such as submarine flow noise from random noises. It therefore tends to be used for the initial detection of a submarine target and for analysing the movement of the target relative to the searcher. It is most valuable where the noises emitted by the target exceed the ambient noise level when it makes possible rapid target detection as well as providing relatively accurate target bearings. New techniques such as transient acoustic processing – the detection and analysis of sudden brief noises such as a weapon launch or random machine noises – are adding to the effectiveness of

Left: HMS *Onslaught* with the somewhat elderly bow-mounted Type 2007 sonar. This class is also fitted with the Type 186 conformal array and the Type 197 sonar intercept/DF set atop the sail.

Below: HMS *Opossum*, one of nine Oberon class submarines being modernised by the fitting of the Type 2051 Triton sonar, which includes a clip-on towed array and new streamlined bow dome.





broad-band processing.

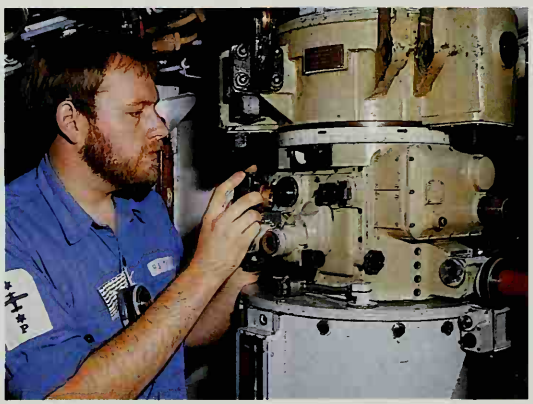
Passive hull-borne sonars normally use the same arrays as the active systems and with a spherical submarine array using digital steering a coverage of some 270° horizontally and 50° vertically can be obtained. Towed arrays now being used by submarines comprise large numbers of hydrophones – several hundred in some cases. The BQQ-25 system used by the US Navy's Los Angeles class SSNs, for example, has a cable 2,624ft (800m) long and 0.37in (9.5mm) in diameter, which is tapered at both ends to reduce drag. The array contains the hydrophones and electronics, which include a multiplexer to reduce the wiring running through the towing cable. The manoeuvrability of the towing submarine is limited, as the array needs to be straight to obtain a coherent signal, and speed is also restricted since arrays oscillate above a certain speed, generating false readings and giving out signals detectable by other hunters. One particular advantage of towed arrays for submarines is that they provide a rearward-looking capability not available by any other means.

For submarines, the problem of stowing towed arrays is a serious one. Many classes have the cable clipped on by specially-trained divers as they leave harbour on patrol and removed as they return: although an apparently slow and clumsy method, this is a simple solution which has the added benefit of reducing the number of arrays needed, as they can be transferred from one submarine to another. The Los Angeles class boats, however, stow their BQR-23A STASS (Submarine Towed Array Sonar System) arrays in long tubes installed between the pressure hull and the outer casing, with the winch in the forward ballast tank.

The Soviet Navy also uses towed arrays, and has developed a series of installations. In one, a large pod containing the array and winch is mounted atop the vertical rudder on submarines such as those of the Victor III and Sierra classes. This pod will undoubtedly generate both noise and hydrodynamic drag, and another type of fitting consists of an array dispensed from a comparatively narrow tube on top of the vertical rudder, with the storage drum and winch clearly inside the hull itself. This device has only been seen so far on the latest unit of the Oscar class SSGN.

Above: Barr & Stroud 254mm attack periscope. Primary quantities in periscopes are size of lens and tube length; the former determines light gathering capability, the latter periscope depth.

Above: Barr & Stroud 254mm search periscope. Such modern periscopes can incorporate image intensifier, thermal imager, low-light TV camera, still camera and laser ranging.



Above: An RN photographer fits a camera to a periscope. Polaroid or 35mm cameras can be used for intelligence gathering; time and bearing data are injected automatically into each frame.

PERISCOPES

All submarines are fitted with periscopes, which in the early days were the only means by which a submerged boat could sense its surroundings. Normally two periscopes are fitted, one for general use and a second, much smaller device for attacking surface ships. Periscopes create two problems for submariners. The first is that in use the head of the periscope is obviously above the surface of the sea and either the tube itself or the wake it generates is detectable both visually and by radar. The second is that in order to use the periscope the submarine must be close to the surface, which makes it more vulnerable than it is at depth, and great care and efficient control surfaces are needed to maintain the boat at the correct depth: it requires only a very minor miscalculation or a sudden change in trim as the result of a torpedo launch for the fin or even part of the hull to break the surface.

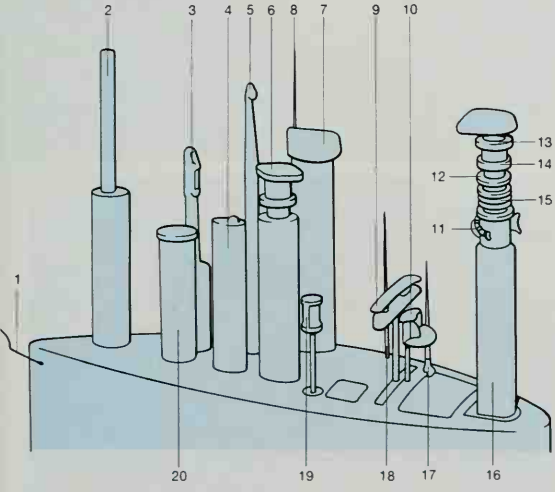
The tube, like any long device moving through a liquid, vibrates. Vibration normally starts at about 10 knots depending on the exposed length, rigidity and supporting structure of the tube. A submarine

Above: Two photographs taken through HMS *Oberon*'s periscope of the West German Bremen class guided missile frigate *Karlsruhe*. The photographs have exceptional clarity.

Right: Sail of a Soviet Kilo class, diesel-electric submarine. The forward mast is the search periscope, while the after mast carries an ESM device. The cage antenna is for direction-finding.

Below: The comprehensive fit of antennas and sensors mounted in the sail of a USN Sturgeon class SSN. The relative heights of the masts and length of fairwater are not in true perspective.

Sturgeon class antennas and masts



1 AS-1554/BRM(20) floating wire antenna
2 AS-1792/BRA-21 helical antenna
3 Observation periscope
4 AS-1201/BPX IFF/UHF antenna
5 Attack periscope
6 AS-1907/BRD-6 direction-finding antenna
7 Snorkel induction mast
8 AT-497/BRC snorkel whip antenna
9 AS-1640A/BPS-14 surface search radar antenna
10 Masthead light
11 AS-994/BLR directional antenna
12 AS-1584/BLR omni-directional antenna
13 AS-1071A/BLR directional antenna
14 AS-1649/0 omni-directional antenna
15 AS-962/BLR directional antenna
16 ECM/DF antenna mast
17 AT-774A/UR portable emergency whip antenna
18 AT-441/MRC portable emergency whip antenna
19 Identification beacon
20 AT-317F/BRR loop antenna

commander will frequently find himself torn between the wish for a long tube to enable him to keep the submarine at greater depth and a short tube which will not vibrate until higher speeds are reached, so that he does not need to slow down if he wishes to make observations during an attack run. The periscope lens is like that in a camera: the larger the diameter the better the field of view and the more limited the precision, and vice-versa, while the greater is the diameter of the periscope tube the greater are the turbulence and surface wake it will generate.

Like so much defence equipment these once straightforward devices are now highly sophisticated. The optical systems normally include split eyepieces to give a quasi-optical effect to reduce eyestrain, while bearing and range are estimated by a microprocessor and fed automatically into the fire control system. Various displays and data are injected into the eyepiece, and a laser rangefinder is frequently included in the attack periscope system, giving an accuracy of ±3ft (1m). Search periscopes can include artifical horizon sextants designed to take extremely rapid sights to update the boat's inertial navigation system, sensors to give warning of electronic threats, and either thermal imagers or image intensifiers to give bad-weather and night capabilities. A TV camera can also be installed to enable more than just one operator to see what is being observed.

ELECTRONIC SENSORS

Modern submarines carry a considerable range of sensors and other devices mounted on extendible tubes in addition to the traditional periscopes, schnorkel and diesel exhausts. The fin array can include radio antennas matched to various frequency bands, radio direction finding antennas, and surface- and air-search radars. The fins of the Los Angeles class boats, for example, contain no fewer than 12 masts of various lengths and diameters. Soviet submarines have similarly comprehensive arrays.

Air- and surface-search radars, essential for submarines running on or near the surface, use small rotating antennas mounted on masts. A widely used example is the French Thompson-CSF Calypso III, an I-band set with an output power of 70kW and a claimed range of 20nm against a 1m^2 airborne target. Performance against surface targets is limited somewhat by the lack of height of the antenna.

Such masts have always been capable of withdrawal into the fin. The traditional practice of leaving the top of the fin exposed, however, results in considerable turbulence and consequent noise so modern submarines have remotely controlled hatches which cover the recesses when the various masts are not in use. This is particularly noticeable on Soviet submarines.

Communications

Communication with submerged submarines has been a problem since the earliest days. Initially there was none at all, but since they depended on stealth for success and survival this suited submariners well. There has, however, always been a need for the fleet commander to pass orders, to update intelligence and to receive information in return. Unfortunately, the unique nature of the oceans, which creates difficulties in other spheres such as detection, also impedes communications.

The general nature of the technical problem is quite simply stated: the oceans attenuate radio waves and the higher their frequency the greater the loss in strength. In addition, radio waves are refracted and diffracted in the same way as sound waves, so the best form of communication to a submerged submarine is a radio signal of very low frequency, but an immutable law of communications is that the lower the frequency the lower are the information content and the speed of transmission. It follows that the most reliable communications are achieved when the submarine is on or very near the surface, but this lays the submarine open to detection by nearby surface units, by satellite or by radio direction-finding.

VERY LOW FREQUENCY RADIO

The VLF band lies between 3kHz and 30kHz and can be received at depths of up to 50ft (15m). Submarines are normally fitted with two types of antenna systems to receive VLF transmissions. The first is a long trailing wire antenna; in the US Navy uses wires some 1,673ft (510m) long. The second is a loop antenna mounted in a plastic buoy, which is unreeled by a slow-moving submarine at its operating depth. Although this reduces the submarine's chances of being detected, such an antenna system is itself vulnerable, because the wire vibrates as it moves through the water, emitting acoustic signals which are detectable by sonar, while the buoy, if very close to the surface of particularly clear water, may be detected visually from the air.

Shore-based VLF transmitting antennas are big, vulnerable and expensive. According to published information, the US has seven major VLF transmitting stations, while the USSR has ten, of which five have transmitting power greater than 100kW, plus 16 smaller stations. NATO has two VLF transmitters and the British one 15kHz station at Rugby. The US Navy also has the TACAMO airborne ELF system described below.

EXTREMELY LOW FREQUENCY RADIO

The ELF band covers the range 300Hz to 3kHz and has been received by submarines at depths of up to 328ft (100m), although it is claimed that depths of up to 1,300ft (400m) are feasible using advanced reception equipment and antennas. ELF is also relatively invulnerable to jamming and nuclear explosion effects, which makes it eminently suitable for communicating with second-strike SSBNs. There are, however, two major problems, the first being that the information transmission rate is very low. The US Navy Seafarer system proposed in the 1970s would have had a transmission rate of only about 10 bits per minute, while the later Austere ELF system is said to require 15 minutes to transmit a three-letter group. It is claimed, however, that by using highly compressed codes some 17,500 different messages can be communicated using three-character groups.

In some of the earliest US trials, in 1963, USS Seo Wolf used a

Above: The US Navy's extremely low frequency (ELF) test facility at Clam Lake in Wisconsin. ELF is highly survivable, but it takes 15 minutes to transmit a three-letter group; even so, some 17,500 different messages can be sent using highly compressed codes.

Right: The first flight of the prototype Boeing E-6A TACAMO on February 19, 1987, was a 30-minute ferry trip from Renton to Seattle. The E-6 is scheduled to replace the EC-130A/Q aircraft, some of which have been in service for many years.

Below: A US Navy crew tests the facilities in a mock-up of the E-6A's very spacious communications centre. The TACAMO system provides communications links between the National Command Authority and the Poseidon and Trident SSBN fleet.

1,000ft (304.8m) trailing wire antenna to detect test signals at 250Hz, 156Hz, 125Hz and 78Hz. With the antenna at a depth of some 30ft (9m) reception was achieved at a range of 1,720nm (3,200km), but the range dropped to some 500nm (850km) when the antenna was taken deeper.

The second problem is that the land-based antennas cover such a large area that their positioning becomes a major difficulty, particularly in the West. The US Navy's Sanguine system, designed in the 1960s, would have had an antenna array covering an area of some 6,564 square miles (17,000km^2), while the much less ambitious Seafarer system would have covered some 3,088 square miles (8,000km^2).

In the 1970s the US Navy set up a test facility at Clam Lake, Wisconsin, which used telephone poles to carry an X-shaped centre-driven antenna, each arm of the cross being seven miles (11.25km) long, with a transmission power of only two watts. In 1976 a submarine travelling at a speed of 16 knots at a depth of 427ft (130m) under 33ft (10m) of Arctic sea-ice received signals from Wisconsin. This test facility is already used for operational message traffic and is to be used in combination with a second site at K.I. Sawyer AFB, Michigan, to provide a full operational system by FY88. This is far short of what the US Navy wants, but is a distinct improvement on what exists now.

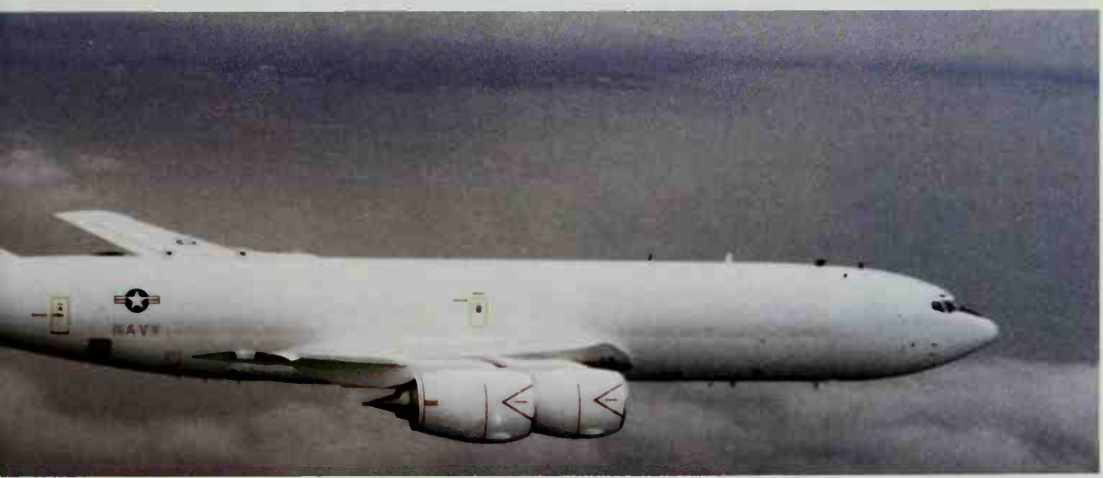
TACAMO

The US Navy's operational TACAMO (Take Charge and Move Out) system, its primary current means of communication with submerged submarines, especially SSBNs, is regarded as being far more survivable than any other. The system is based on Lockheed EC-130A/Q Hercules aircraft deployed in two squadrons, one responsible for the Pacific and the other for the Atlantic. The aircraft act as airborne radio relays between the National Command Authorities and the submarines, using various transmission means in the VLF, LH, HF and UHF bands. VLF transmissions are achieved using a 200kW transmitter and a trailing-wire antenna some 6.2 miles (10km) long, with a drogue parachute at the end. When it becomes necessary to transmit the aircraft is flown in a continuous tight circle, which results in over 70 per cent of the wire hanging straight down and acting as a relatively efficient vertical antenna. One aircraft is airborne over each ocean at any time, with another at 15 minutes' notice on the ground. Missions last around 10 or 11 hours, of which about seven are spent loitering on station, and make random use of suitable airfields.

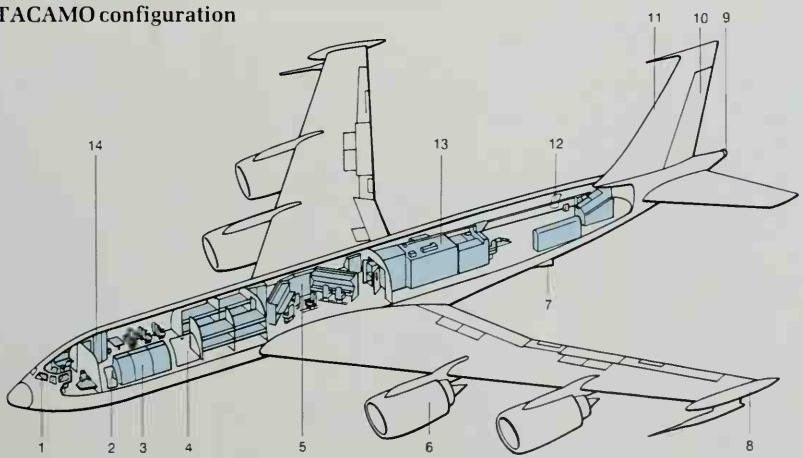
The TACAMO fleet currently comprises a few EC-130A aircraft and rather more EC-130Qs, a total of around 20 airframes. A new airframe, the E-6, based on the well-proven and widely used C-135 is under development and will enter service in 1989. This aircraft will fly at 25,000-30,000ft (7,620-9,144m) and its VLF antenna will be 26,000ft (7,925m) long. Fifteen aircraft are to be procured at a system cost of some $2,000 million.

COMMUNICATIONS BUOYS

Various types of buoy are used to communicate with submarines. One example is the SSQ-86 (XN-1) down-link communication (DLC) buoy, which is used to transmit a programmed message to a submerged submarine without the



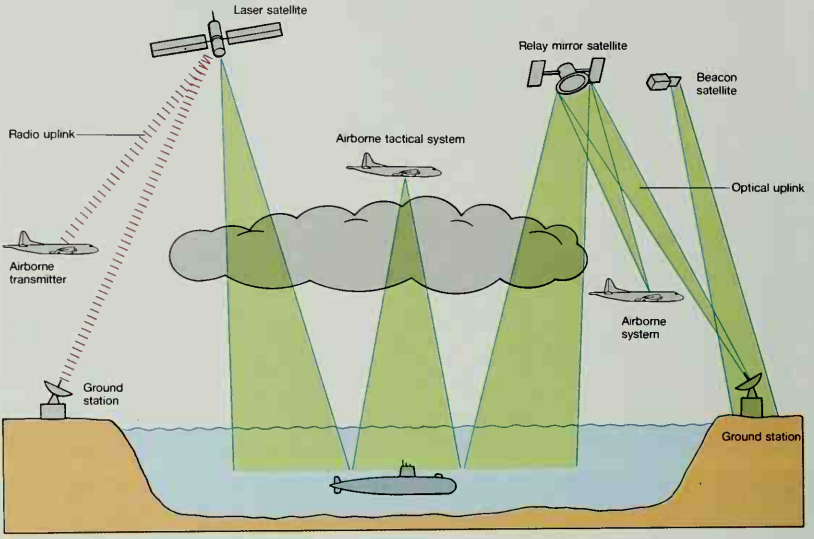
E-6A TACAMO configuration



1 E-4B-type electromagnetic pulse (EMP) resistant windshields
2 E-3A escape chute and spoiler have been deleted
3 VHF/UHF and HF radios; altitude alert, windshear and other systems
4 EMP-hardened 707-320 cargo door
5 Operators' stations
6 CFM-56 engines with 72-hour engine oil tanks
7 Long-wire drogue nest
8 Wingtip satellite antenna
9 Short-wire drogue nest in tail cone
10 Improved rudder boost
11 HF2 shunt antenna
12 Door modified for bailout
13 TACAMO mission equipment installed in place of E-3A equipment
14 Electronic support measures display added at navigator's station display

Above: The Boeing E-6A is yet another version of the ubiquitous Boeing C-135, the military progenitor of the civil 707 airliner. Total cost of the 15-strong force will be $1,600 million, and eight aircraft are earmarked for the Pacific and seven for the Atlantic fleets. The AWACS airframe is utilised, but without the rotodome and pylon. Generating plant gives radiated powers of some 200kW and a 2.5-mile (4km) trailing-wire antenna is deployed from a drum in the tail.

Submarine laser communications



Above: For strategic communications to subs, the Americans propose to use space-based (left) or ground-based (right) blue-green lasers to penetrate the ocean.

Above: Aircraft can communicate with submarines using buoys such as this Sippican SUS Mk 84, which is 15in (38cm) long, 3in (7.62cm) in diameter and weighs 6.5lb (2.95kg). Pulsed 3.5kHz and 2.95kHz tones pass messages such as: "emergency, stay down", "unknown submarine: surface to be identified" and "establish communications".

Right: The XSTAT expendable tactical transceiver enables submarines to establish two-way communications with aircraft on a 350MHz UHF-AM frequency over ranges, depending on the aircraft's altitude, of up to 100nm. The system uses a buoy launched from a standard tube in the submarine: a lifting body tethered to the submarine hull contains a reel of wire attached to the buoy, which rises to the surface; the buoy also has spooled wire, the two spools giving torsionless pay-out. Once on the surface the buoy provides up to one hour of two-way voice communications.

submarine revealing its position. Mounted in a standard A-sized sonobuoy, the DLC buoy can be launched from any suitably equipped aircraft, or simply thrown overboard from a surface ship. The message, consisting of a maximum of four groups of three characters, is programmed into the buoy using a single push-button switch. On entering the water the buoy transmits the message once near the surface then descends to a predetermined lower depth where it transmits a second time, pauses for five minutes at the same depth, transmits a third time and then scuttles itself. The whole process from water entry to scuttling takes about 17 minutes.

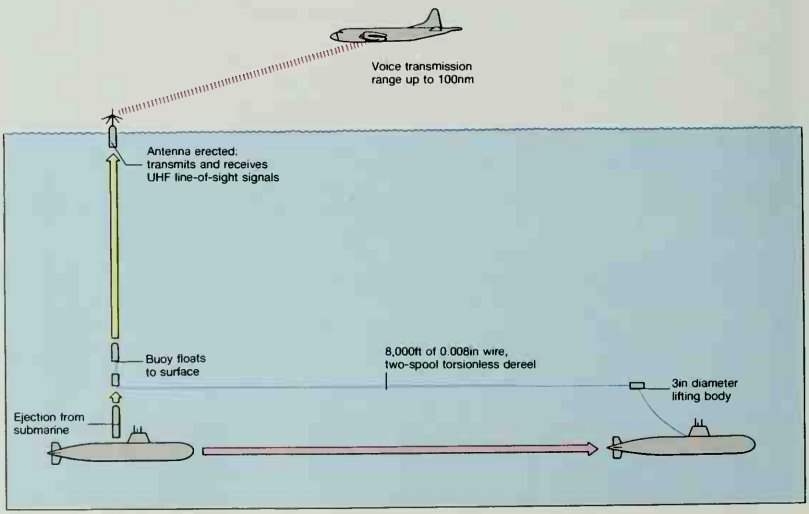
BLUE-GREEN LASERS

There is an optical window in the blue-green part of the spectrum which enables transmissions to penetrate the ocean a substantial distance. The main problem is that the power requirements are considerable and satellites are not yet capable of carrying equipment of the necessary power. However, this difficulty may be overcome by using a ground-based laser in conjunction with a space-based mirror, with adaptive optics being used to produce a cohesive beam. Such a system could have a data rate up to 300 times better than that of an ELF system, but would not penetrate to the same depth. One interesting aspect of such a system is that while an aircraft which unintentionally passed though such a beam would not itself be in any danger, aircrew and passengers without laser glasses could suffer eye injuries.

COMMUNICATION FROM SUBMARINES

Any transmission, whatever part of the electromagnetic spectrum it uses, is liable to interception by hostile agencies and so risks giving away the submarine's position. For many years submarines could only transmit using the high frequency (HF) band (3-30MHz), which is relatively easy to intercept and to use for direction-finding (DF). The German Navy in World War II used

Sippican XSTAT operation


Voice transmission range up to 100nm
Antenna erected: transmits and receives UHF line-of-sight signals
Buoy floats to surface
8,000ft of 0.008in wire, two-spool torsionless dereel
3in diameter lifting body
Ejection from submarine

Left: A US Navy UH-1 helicopter hovers over the exposed periscope masts of a submarine, achieving optimum communications conditions.

Left: For the full range of standard radio communications submarines need mast-mounted antennas. Seen here under test at the UK National Maritime Institute is a hydrodynamic, non-hull penetrating integrated communications mast made of glass-reinforced plastic which the designers, Plessey Naval Systems, claim will improve communications performance and permit more flexible operating.

Below: Communications between submarines are particularly difficult; sonar can be used, but it reveals the submarines' presence. It is rare for two submarines to meet on the surface in mid-ocean, but this Soviet Victor III SSN (foreground) and Oscar SSGN did in the North Atlantic in 1985.

to exchange considerable amounts of radio traffic between its headquarters and the boats at sea; the transmissions from the HQ were monitored and, because the Enigma codes had been broken, the Allied hunting forces frequently knew as much about the U-boats' instructions as the latter did themselves. Further, because of the demands by Dönitz' HQ for information, the boats were forced to transmit at sea and could be DFed with ease and hunted down. Once the Germans appreciated this they took a variety of steps to minimise transmission times, some of them procedural but one of which was a technological means – the Kurier burst transmission system – whereby the information was compressed electronically and then transmitted in a very short squirt transmission. Such HF burst transmissions are still used; they are by no means undetectable, but they do make the interceptors' job much more difficult. The HF antennas are mounted on extending masts carried in the submarine's fin.

Satellite communications in the UHF and SHF bands are a boon to submarines, as transmissions are much less easy to detect from ground monitoring stations, although they can be detected by suitably equipped aircraft and by other satellites. Most submarines now carry mast-mounted satellite antennas which can be used when running on the surface or at periscope depth.

If real-time communications are not essential then transmitting buoys such as the US Navy's BRT-1 can be used. Containing a cassette recorder and radio transmitter, this device is released by the submarine and when on the surface transmits a message of up to four minutes' duration, with a preset delay of between 15 and 60 minutes. With a one-hour delay in transmission, a submarine travelling at 20 knots could be anywhere in an area of 1,664 square miles (4,310km^2) by the time transmission takes place.

Communications to surface ships and to other submarines are just as much of a problem. Buoys such as the BRT-1 can be used to pass messages which are not time-urgent to ships, and in certain circumstances acoustic underwater telephones can be used. Otherwise, communications to other submarines, must be passed back to base for retransmission on the normal fleet broadcast services.

Surface Antisubmarine Warfare

There is considerable discussion in most navies on the most effective way of combating submarines. Submariners themselves are almost unanimous in their view that the best anti-submarine platform is another submarine, while surface mariners and aviators tend to maintain that a combination of warships and aircraft in conjunction with area surveillance systems such as SOSUS give the best results. The use of submarines in anti-submarine warfare is described elsewhere; this chapter deals with the technology of surface warships and aircraft in the ASW battle.

ACTIVE SONAR

The primary means used by surface warships over the last 30 or so years to find submarines has been active sonar. The sonar dome in a warship is mounted either in the bow or under the ship's keel and a particular problem for such hull-mounted sonars is the self-noise generated by the relative movement between the acoustic transmitter-receiver and the water surrounding it.

Active sonar systems comprise large numbers of transducers mounted in arrays. Surface ships use flat circular or rectangular arrays; a typical modern system, the US Navy's SQS-26, has 576 transducer elements in a cylindrical array, housed in a large bulbous dome at the foot of the stem. The presence of such a bow-mounted sonar is usually indicated by a sharply overhanging bow, as on most US and Soviet ASW ships, whereas a less acute bow angle, such as those seen on British ships, normally indicates a sonar dome mounted in the keel. All these arrays are fixed and beams are formed electronically to give directional resolution, while Doppler shift in the return signal gives moving target indication.

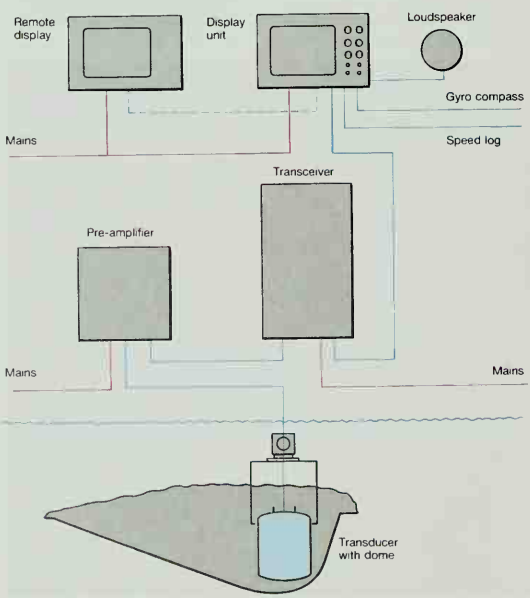
Developments in active sonar for surface ships are aimed at maximising its excellent detection capabilities while trying to reduce its characteristic and revealing signature. The principal methods under investigation are spread-spectrum transmission, parametric sonar as described in the chapter on sensors.

PASSIVE SONAR

The major drawback of active sonar has always been that it reveals its presence to the target. A submarine will normally detect a surface warship's active sonar transmissions long before the warship itself realises a target is there, and while the presence of an anti-submarine aircraft is very difficult for a submerged submarine to detect, its proximity immediately becomes apparent when an active sonar buoy starts to transmit. Passive sonar is, therefore, growing rapidly in importance since, because it makes no transmissions, it ensures that it does not betray the hunter's position.

Hydrophones are often deployed in towed arrays, which limit the speed and manoeuvrability of the towing ship, making it very vulnerable

Simrad SS242 sonar system



Left: Simrad SS240 series sonars are designed for installation in small surface ships. The transducer is mounted inside a dome and received signals are passed via a pre-amplifier to a transceiver. An operator's display unit and loudspeaker correlate inputs with data from the ship's gyro-compass and speed log, and remote displays can allow the situation to be monitored at other localities, such as the bridge.

Above: The multicolour display of a Simrad SS304 sonar, designed for installation in ships down to 150 tons. The −17° tilt angle (A) and 85° ping sector (B) of the sonar are shown, together with own ship's track (H), position marker (G) and actual position (F). The target's position (D), speed and direction (E) and depth (C) are also displayed, along with other underwater echoes such as fish shoals (I) and navigation data.

itself. The problem is heightened by the need for separation from the main body of a task group to maximise sonar performance: as was shown by British radar picket ships in the 1982 South Atlantic war, such isolated ships are highly vulnerable to air attack. Finally, the towed arrays themselves may give rise to detectable noise either from water-flow over the array or by the towing cable resonating at its 'natural' frequency, and processing electronics must be able to discard such signals.

NON-ACOUSTIC SENSORS

A submerged submarine moving through the water leaves a wake which is detectable by active sonar. This turbulence, conical in shape, eventually reaches the surface well astern of the boat, where it causes minute variations in the wave pattern. Both the USA and USSR are experimenting with over-the-horizon backscatter (OTH-B) radar in an effort to detect

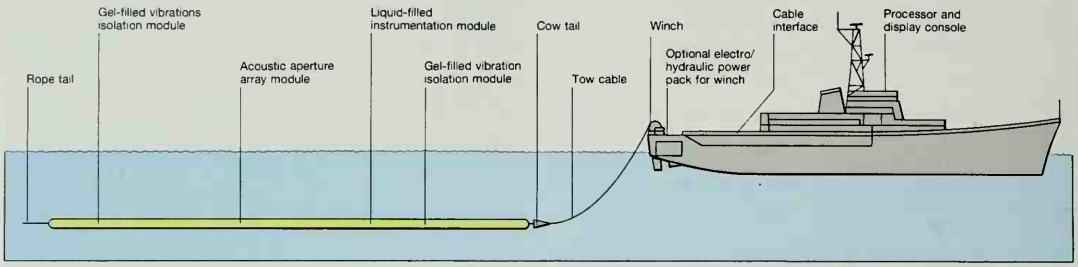
Left: Graseby 750 sonar operators' console featuring three displays for (left to right) the Plan Position Indication, Doppler Display and Hydrophone-effect Passive Search Subsystems. Displays are stabilised geographically and supplemented by audio systems.

Above: Transducer arrays are mounted in hydrodynamic glass-reinforced plastic domes to minimise flow noise; the domes may be mounted either at the bows or on the keel amidships. This example is manufactured by Plessey Naval Systems.

Above: Plessey PMS 40 series surface ship sonar array, with 12 transducers in each vertical stave. This array provides omnidirectional simultaneous active and passive operation, and the electronics allow automatic tracking of up to ten active contacts.

Below: The three-man operators' console of the Plessey Type 2016 sonar system, current major fleet escort sonar of the Royal Navy. Electronic analysis and presentation of information is essential to enable the crew to make proper assessments of target data.

Plessey COMTASS (Compact Towed Array Sonar System)



Above: The British Compact Towed Array Sonar System (COMTASS) provides a passive ASW capability for surface ships and submarines. Towed arrays are very effective, though they limit the speed and manouevrability of the towing ship.

Right: HMS *Cleopatra* with her Type 2031 towed array deployed. Such arrays need large stern installations, and her sister ships needed sponsons to mount the winch, adding 3ft (1m) to their length, but *Cleopatra*'s installation is within existing deck space.

this phenomenon at considerable ranges. Depending on the depth of the submarine and the prevailing oceanic conditions the wake turbulence may also force colder water to rise and mix with warmer water at the surface, causing a temperature differential detectable by satellite or aircraft-borne sensors.

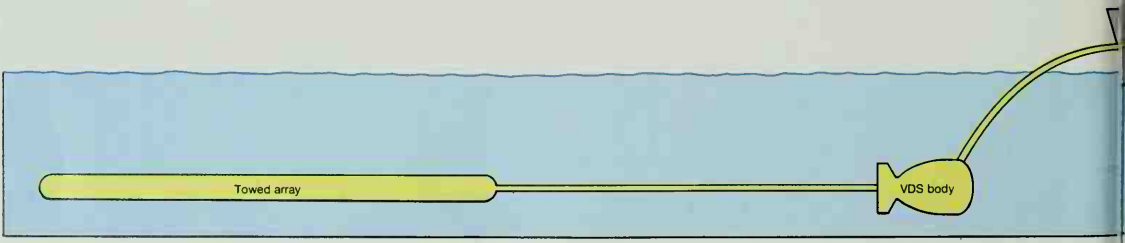
When a submarine is travelling near the surface there is a tiny but perceptible rise in the surface level of the water above the hull which is potentially detectable by satellites. The USSR is known to be interested in this technique and the USA has at least one satellite, SEASAT, whose radio altimeter has a vertical resolution of 3.9in (10cm) and could be used in this role.

Submarines are also detectable by the electrical and magnetic fields they create. According to a Soviet writer there are electro-chemical processes on a submarine hull which generate varying electrical potentials with currents flowing between them using seawater as the conducting medium. The rate of change of the consequential electrical and electromagnetic fields is detectable by sensitive devices, among which would be very large seabed coils.

A submarine hull is a mainly ferrous body which moves through the lines of force of the Earth's natural magnetic field, creating a magnetic anomaly which is detectable by airborne magnetic anomaly detector (MAD) equipment. MAD units are mounted in extensions behind the tails of fixed-wing aircraft or in aerodynamic bodies, or birds, towed by cables behind helicopters. All advanced anti-submarine aircraft are fitted with such devices, including the American P-3 Orion and S-3 Viking, British Nimrod, French Atlantic and Soviet Il-38 May. MAD devices normally have a maximum detection range of about 1,000ft (305m) and are, therefore, unsuitable for area searches, but they are invaluable for the precise

EDO SQR-18A(V)1 TACTAS (Tactical Towed Array Sonar)

Below: The widely used SQR-18A TACTAS towed array system consists of three subsystems. The towed subsystem itself comprises an armoured cable, with an array of acoustic modules, and is shown here in its (V)1 form attached to an existing VDS (variable depth sonar) sonar body; in the (V)2 form, for ships with no VDS, the length of cable in relation to the ship's speed determines array depth. The tow cable spatially isolates the array from own-ship noise. The handling and storage subsystem comprises a hydraulically driven winch and operator's console installed in a stern compartment below decks, while the electronics sub-system provides the control and display functions. A signal conditioner provides gain and equalisation and converts the analogue signal to digital; the beam-former forms multiple search beams and also cancels out own-ship interference. The signal then passes through processors and a tracker to a mass memory, before being displayed to the operator in the ship's operations centre.



Above: The receiver array of the BAe Active Towed Array Sonar. Hydrophones and associated electronics are housed in a 65.6ft (20m) long, 3.46in (88mm) diameter flexible tube. Signals are passed to shipborne electron-ics as a single serial data stream.

location of underwater targets detected by other means, such as SOSUS. However, the use of titanium hulls in the Soviet Alfa class introduces a new factor, as titanium is a non-magnetic material and cannot be detected by MAD sensors. Fortunately for the users of MAD, titanium is so expensive, and the fabrication techniques involved in its use are so complex, that only a very small proportion of the world's submarines are ever likely to be constructed of this metal.

UNDERWATER OPTICS

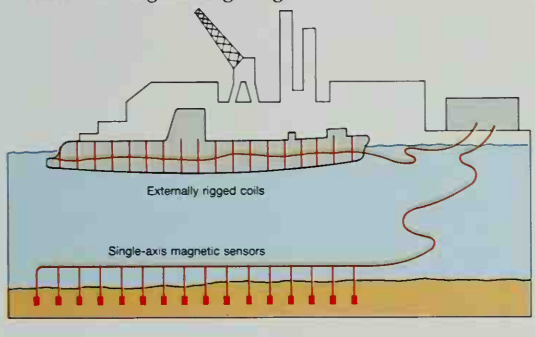
Seawater is an efficient light absorber, but there is a window in the blue-green portion of the visible spectrum. Efforts are being made to exploit this for communication purposes with blue-green lasers, using satellites to project the beam onto the target area, as described in the previous chapter. A similar technique could be used to detect submarines, either by detecting minute return reflections from a satellite-borne sensor or by mounting a blue-green laser and suitable detectors in an ASW aircraft. In the latter case laser detection could well be complementary to MAD, and would overcome MAD's inability to detect titanium hulls.

ELECTRONIC WARFARE

It has been described elsewhere in this book how diesel-electric submarines are inherently vulnerable to detection, because they must approach the surface and expose their snorkel heads at regular intervals to recharge their batteries and replenish their life support systems. Nuclear-powered submarines do not have to expose snorkel masts, but they share with diesel-electric submarines the problem of communications, and surface anti-submarine forces are naturally quick to exploit this weakness. The primary means of communicating with a totally submerged submarine is by VLF radio, but the long towed antenna essential for reception is detectable by surface warships and aircraft. Not surprisingly, major efforts are being made to develop new communications systems for submarines.

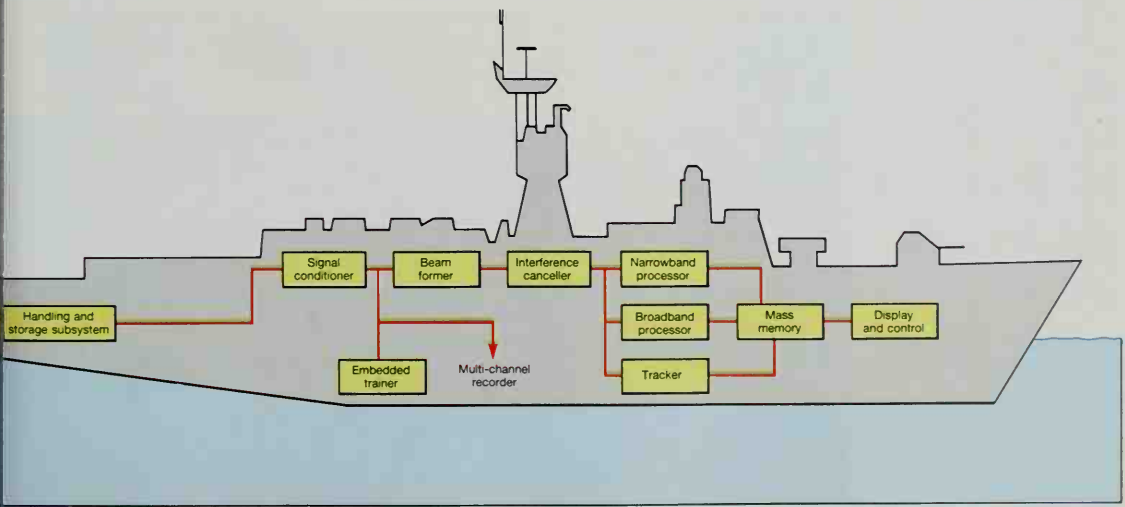
Radio transmissions by submarines are, of course, immediately detectable by electronic surveillance using platforms such as satellites, shore-based monitoring stations, surface warships and aircraft. All will seek first to pinpoint the site of the transmission, then to identify the transmitter and finally to analyse the content of the signal. One way submarines endeavour to overcome this is by detaching transmitters in buoys which are released at normal operating depths and do not transmit until they reach the surface.

Thorn EMI degaussing range



Above: During ship construction and in normal operation a ship or submarine becomes magnetised, with the three major elements being vertical, longitudinal and athwartships. It is therefore essential that they be treated on a degaussing range, one type of which is shown here, using sheltered water near a naval base so that handling facilities and electrical power can be utilised.

Above: Not surprisingly, the US Navy's silencing facilities for its submarine fleet are much more sophisticated and expensive than those shown on the left. Here USS *Ohio* (SSBN 726) is seen inside a huge, purpose-built structure being treated to reduce her magnetic and other signatures to the lowest feasible level, prior to going on an operational patrol. The Soviets have similar facilities.



ANTI-SUBMARINE ROCKET LAUNCHERS

Many navies mount anti-submarine rocket launchers on surface warships, despite the inherent disadvantage – shared with depth charges – that their short range allows the target to come too close. The Soviet Navy has a series of devices designated *Raketnaya Bombometnaya Ustanovka* (rocket depth-charge launcher) whose designation suffixes indicate their range in metres. The most elaborate is the RBU-6000, which consists of 12 vertically loaded barrels arranged in a horse-shoe shape, on a mounting which can be both trained and elevated. The rockets are fired in a paired sequence; their maximum range is 6,562 yards (6,000m) and the warhead is 121lb (55kg) of high explosive. RBU-6000 is fitted in ships ranging in size from Kiev class aircraft carriers to Grisha class corvettes. Others in the series are the RBU-2500 (16 barrels), RBU-1200 (five barrels), RBU-1000 (six barrels) and RBU-600 (six barrels).

The only similar device in wide-scale use is the Swedish Bofors 375mm ASW rocket-launcher, which uses two types of rocket: one has a range bracket of 656-1,750 yards (600-1,600m) and the second of 1,750-3,940 yards (1,600-3,600m), the former designated Erika and the latter Nelli. The Bofors launcher comes in two-, four- and six-tube versions, and the six-tube version is used by the French firm of Creusot-Loire as the basis of its Model 1964 launcher.

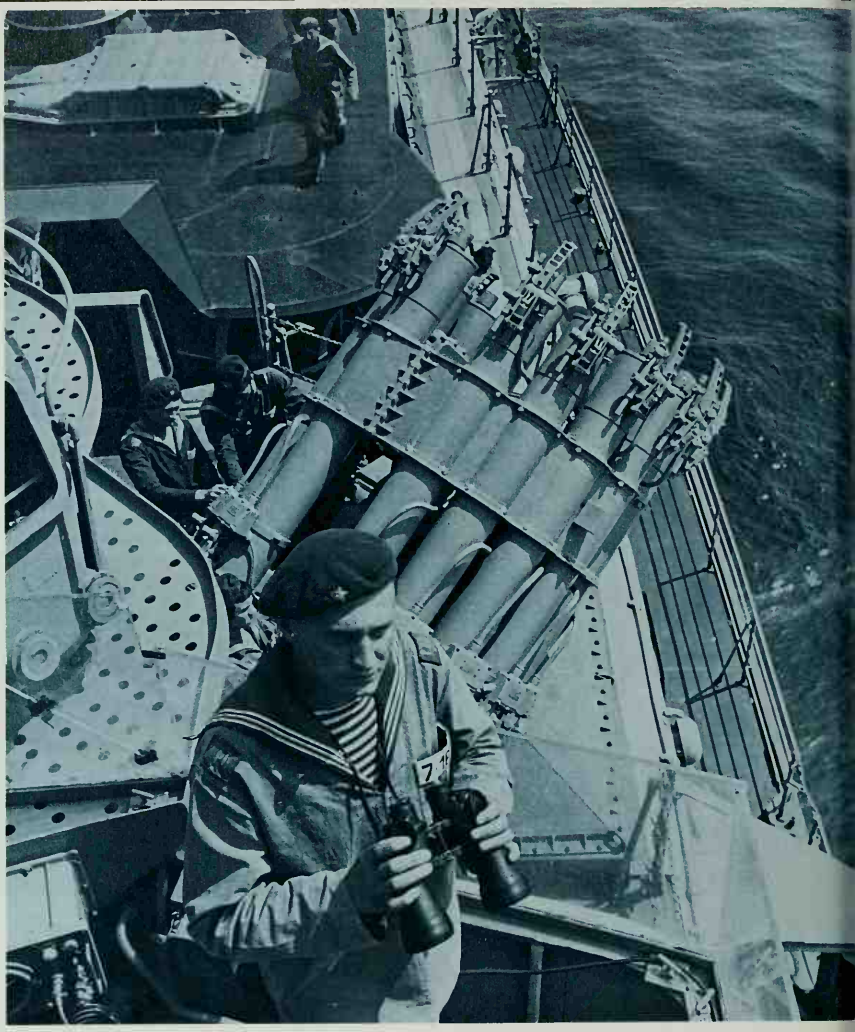
MINES

Mines have a major role in anti-submarine warfare, though the days of the moored or bottom-sitting mine are probably numbered. Far more effective is the US Navy's Captor (Encapsulated Torpedo), which is designed exclusively for attacking submarines. Captor consists of a Mk 46 torpedo housed in a tube; laid by submarine, aircraft or surface ship, it sits on the ocean floor and monitors all passing maritime traffic using passive sonar equipment with a range of some 3,000ft (1,000m) which is gated to exclude surface traffic. On identification of a submarine target the active sonar is switched on, optimum launch time is computed and the torpedo is launched. No IFF is fitted, so friendly submarines must be kept clear of any Captor minefields.

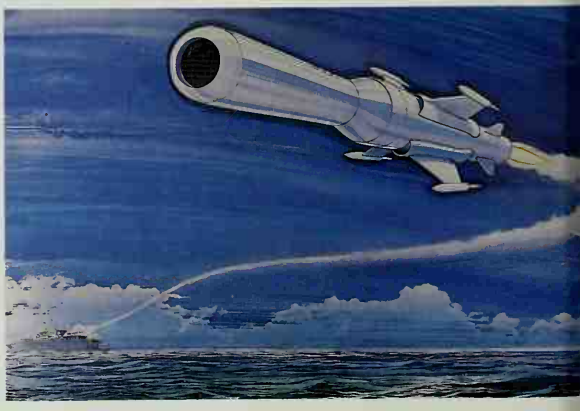
STAND-OFF WEAPONS

To overcome the problem of reaching the target submarine before it can attack its hunter a number of stand-off weapons have been developed which deliver a depth charge or a torpedo by a carrier missile or rocket. The US Asroc consists of a Mk 46 acoustic homing torpedo with a strap-on rocket motor, and somewhat similar weapons are made in France (Malafon), Australia (Ikara) and the USSR (FRAS-1 and SS-N-14). Ranges are not great; that of Asroc, for example, is estimated to be between 1.25 and 6.2nm (2-10km).

The US Navy is developing a common successor to Subroc and Asroc known as Sea Lance (formerly ASW-SOW). Designed to combat the threat posed by such submarines as the Soviet Alfa and Sierra classes, and with a range estimated at between 35 and 100 miles (56-160km), Sea Lance will be launched vertically from surface ships and expelled from standard torpedo tubes in submarines. The system comprises a common

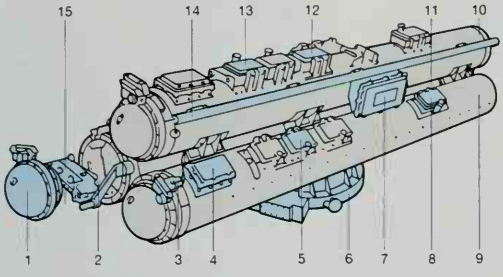


Above: Virtually all Soviet Navy surface warships are fitted with some of the numerous models of *Raketnaya Bombometnaya Ustanovka* (rocket depth-charge launcher). This is the 12-barrel RBU-6000, a device with a 6,561yd (6,000m) range which is fitted in ships ranging from Kirov battlecruisers to Grisha corvettes.



Below: Projected Franco-Italian ASW weapon designed to deliver a torpedo over ranges in excess of 22nm (40km) with in-flight updating capability.

Plessey PMW 49A deck launcher system

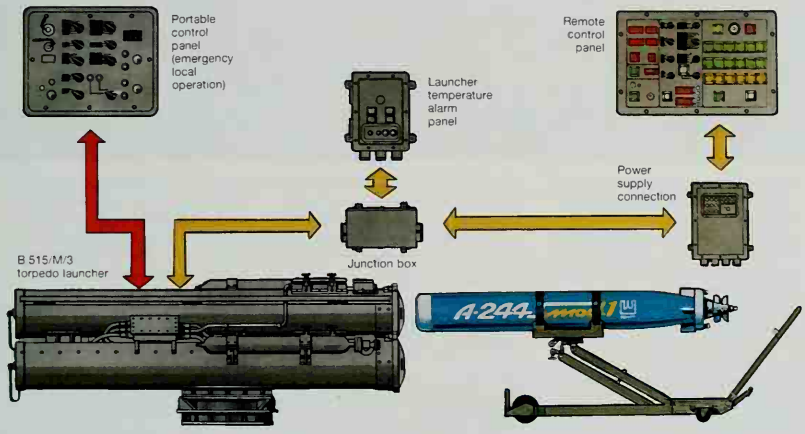


1 Breech assembly
2 Training ring and
3 Locking ring and control lever
4 Control box
5 Hatch No 3 (Mk 46 lanyard solenoid unit)
6 Training mechanism
7 Starboard distribution box
8 Hatch No 1 (Stingray lanyard solenoid unit)
9 Tube No 3
10 Tube No 2
11 Tube No 1
12 Hatch No 2 (Stingray battery port cover remover)
13 Hatch No 4 (containing plug puller unit)
14 Charging hose
15 Torpedo securing beam

Above left: British PMW 49A triple torpedo launcher for lightweight torpedoes such as US Mk 46, British Stingray or Italian A.224S. The tubes are made of epoxide resin embodied with filament-wound glass fibre and have fire-retardant additives.

Above: The STWS antisubmarine torpedo launcher from which the PMW 49A was developed. One of the lessons of the Falklands War was the need for swinging bulletproof plates; these are now fitted outboard of the warhead end of the tubes.

Whitehead A.244/S Mod 1 shipborne system



Above: This lightweight torpedo system by the Italian Whitehead organisation is designed for small ship use and is similar in function to the PMW 49A at the top of the page. The electrically propelled A.244 is 8.86ft (2.7m) long with a diameter of 12.7in (324mm).

Below: Launch of a lightweight torpedo from the STWS (ship's torpedo weapon system) tube aboard a Royal Navy warship.

missile carrying either the Advanced Lightweight Torpedo or a nuclear depth charge. The latter would almost certainly be a new common device to replace the W55, B57 and W44 nuclear warheads currently in service with the US Navy.

TORPEDOES

The general question of torpedoes is discussed elsewhere, their basic problem being lack of speed. Even with helicopters and stand-off delivery systems such as Asroc there is a need for much faster torpedoes; the US Advanced Capability (ADCAP) programme for the Mk 48 torpedo will raise its speed to 55 knots (63mph), while the next-generation British surface warship- and aircraft-launched torpedo – Spearfish – uses a gas turbine and a pump-jet to attain even higher speeds.

Warhead design is critical, particularly in the case of lightweight aircraft-launched torpedoes which, by their very nature, have small warheads and are most unlikely to cause any damage to stronger submarine hulls. In general terms the capabilities of current torpedoes lag behind those of the sonars that support them: they are slow, lacking in range and extremely noisy.

DEPTH CHARGES

The typical World War II surface warship ASW weapon, the depth charge is now little used by surface ships since to allow a modern submarine within launcher range – about two miles (3.2km) – would be very hazardous. However, depth charges are used by ASW helicopters; a good example is the British Mk 11 which contains 180lb (81.6kg) of Torpex. Far more effective, but with major political implications and therefore tactical limitations, is the nuclear depth bomb, though tactical nuclear weapons could be used more readily at sea than on land.

NUCLEAR WEAPONS

The traditional method of attacking a submerged submarine is by detonating an explosive charge on or near its hull. Because the submarine is already in a pressurized and hostile environment, the charge does not need to be big enough to cause a complete collapse of the hull on its own – it needs only cause a relatively minor amount of penetration and then leave the water pressure to effect a totally catastrophic collapse.

A successful attack on a submarine involves delivering a charge of sufficient explosive force within lethal range too quickly to allow the boat to take adequate evasive action. The difficulties are compounded by the relative slowness with which weapons can approach submarines, the increasing effectiveness of submarine sensors, the enhanced agility and speed of the targets and the growing strength of their hulls. Clearly there is a trade-off between the various factors involved, but one way of overcoming the difficulties is to produce an explosive charge so powerful that it need not be particularly close to the submarine to achieve its desired effect, an obvious candidate for such a role being a nuclear weapon. As with acoustic effects, however, the use of nuclear weapons under water is not entirely straightforward.

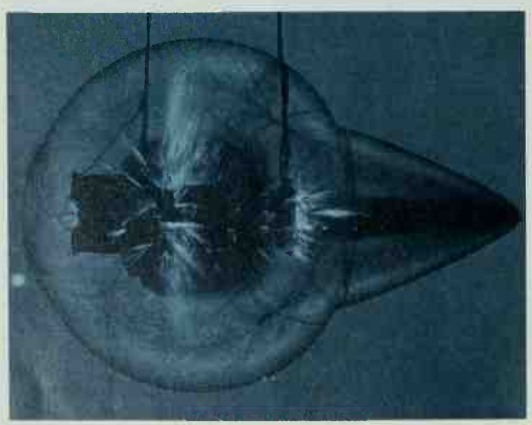
Documentation of the effects of underwater nuclear explosions is highly classified, because such explosions would have only military applications and effects, and consequently very sparse. However, it is known that the USA carried out a series of underwater tests prior to the imposition of the Nuclear Test Ban Treaty, including Test Baker: carried out in July 1946 at a depth of 200ft (61m) in a lagoon, its main aim seems to have been to assess the effects on surface warships. Test Wigwam, carried out in 1958, was of unspecified yield at a depth of 2,000ft (610m), while Test Wahoo, carried out in 1958 at a depth of 500ft (152m), occurred over deep water.

In general terms, a deep underwater nuclear explosion results in limited thermal or nuclear radiation; the principal effect is the formation of a hot steam bubble centred on the explosion. This bubble rises through the water, expanding at a diminishing rate until a maximum size is achieved, and provided it does not touch the bottom or the

Above: USS *Cochrane* (DDG 21) launches an Asroc missile. Such delivery systems are essential if a surface ship is to have any hope of destroying a hostile submarine before it destroys her.

Below: Asroc uses a solid-fuel rocket to deploy a parachute-retarded Mk 46 torpedo or a 1kT nuclear depth charge over maximum ranges estimated at around 10,000 yards (9,600m).

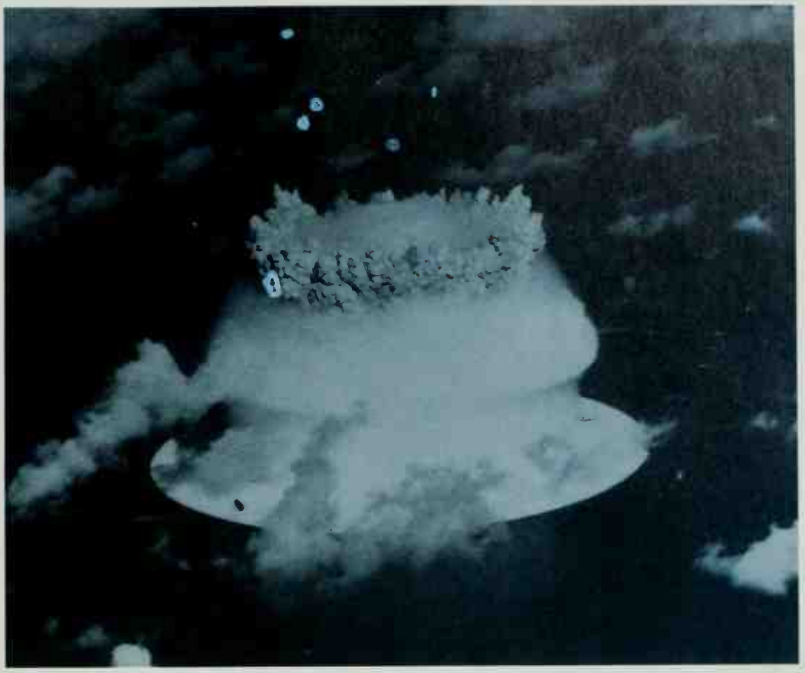
Below: Shadowgraph of a shaped-charge warhead detonating under water; the forward projection of the molten jet – the Monroe Effect – is clearly visible.



All Western antisubmarine weapons may soon have to rely on such warheads to penetrate the exceptionally strong hulls of some current Soviet submarines.

surface, at this stage it is spherical in shape. As a result of the outward momentum of the water surrounding it, the bubble continues to expand until its internal pressure is below that of the ambient water pressure, whereupon the pressure outside the bubble forces it to contract. Now momentum forces it to contract to the point where internal pressure exceeds ambient pressure, some of the steam condenses and the bubble expands once again. Meanwhile, during the contraction phase, the bottom of the bubble tends to move upward more rapidly than the top, due to the difference in hydrostatic pressure, so as the bubble rises towards the surface, expanding and contracting as it goes, it generates a compression or shock wave with each expansion. Each compression is of a lower intensity but greater duration than its predecessor, and a total of three complete cycles seems to be the maximum.

During the pulsation and upward motion of the bubble, the water surrounding it acquires considerable upward momentum of its own, eventually breaking through the surface at a high velocity – 200mph in the Wigwam test. The very rapid expansion of the hot gas bubble results in a compression wave being sent out in all directions with a sharp rise in overpressure at the shock front, and this peak overpressure does not fall off as rapidly with distance as it would in air: for example, peak overpressure at 3,000ft (914m) from a 100kT deep-water burst is about 2,700psi (190kg cm^{-2}), whereas in air the peak would be only 2-3psi (0.14-0.2kg cm^{-2}). Conversely, the duration of the shock wave in water is much shorter than in air – two or three hundredths of a second as opposed to approximately one second.

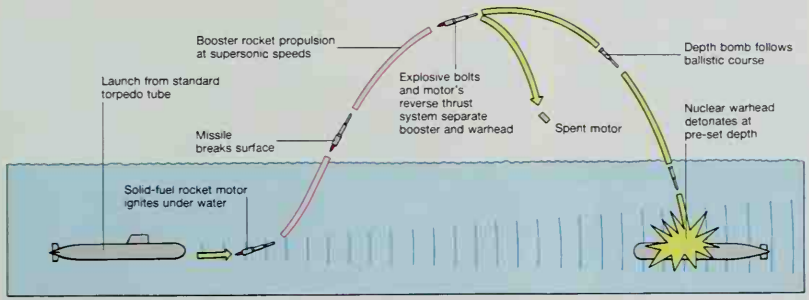


Above: Surface emption caused by an early underwater nuclear weapon test at Bikini Atoll Numerous antisubmarine weapons are armed with nuclear warheads; effects are complex.

There are also two forms of reflected wave and an induced wave. The first reflection is from the surface: where the water shock wave hits the surface it is reflected back as a negative pressure wave and below the surface the sudden change from positive to negative pressure is known as the surface cut-off. The second reflection comes from the bottom, and is a simple compression reflection. Where the bottom is rock or other hard material the shock wave may travel a short distance through this material before being reradiated back into the water. Both the latter shock waves are positive compression waves, unlike the surface reflection.

As in other areas, the nature of the ocean can cause vagaries in the wave paths. With a strong shock

Subroc launch and trajectory profile


Booster rocket propulsion at supersonic speeds
Launch from standard torpedo tube
Missile breaks surface
Solid-fuel rocket motor ignites under water
Explosive bolts and motor's reverse thrust system separate booster and warhead
Spent motor
Depth bomb follows ballistic course
Nuclear warhead detonates at pre-set depth

Above: Mission profile of a Subroc missile. Subroc is due to be replaced by the new Sea Lance antisubmarine stand-off weapon, which will operate on similar principles. Submarine sensors have long had greater ranges than their weapon systems; missiles are gradually righting the imbalance.

Below: Subroc powers away from the surface. In service since 1962, the weapon will remain operational into the 1990s because of delays with Sea Lance.

Above: Plessey Cormorant dunking sonar with the array elements folded away, an arrangement which facilitates rapid deployment.

Above: Cormorant's arrays deployed. Such extending arrays greatly enhance the performance of the sonar, giving greater range and improved definition.

intensity the surface-reflected wave tends to overtake the main shock front, because the latter sets in motion the water through which the following reflection wave is travelling. Also, as with acoustic waves, the variations in density, temperature and salinity can cause underwater shock waves to be refracted and thus either diverted from certain areas or, conversely, channelled toward or even focused on one area to produce a stronger than expected shock wave at some point at a great distance from the detonation.

The effect of an underwater nuclear explosion on a submarine is, therefore, the result of a complex series of activities. There may be up to three compression and rarefaction waves (called bubble pulses), as well as a negative shock wave reflected from the surface plus bottom-reflected and bottom-induced positive waves. The effect on an underwater target depends on the water depth, the explosive yield of the weapon, the nature of the bottom and the time interval between the direct and indirect shock waves, their magnitudes and their positive or negative natures. What is certain is that the sheer explosive power of a nuclear depth bomb or torpedo must give an attacker a much

Left: The reeling machine and transducer of the Bendix AQS-18 airborne sonar system, which is in service with Lynx helicopters of the West German Navy. The similar AQS-13F has been selected to equip the US Navy's new SH-60F Seahawk carrier-based antisubmarine helicopter. The transducer is not as small as it looks, being 49.4in (125.5cm) long, 13in (33.1cm) in diameter and weighing 193.6lb (88kg). The winch gives high deployment and retrieval rates.

Right: A Royal Navy Sea King Mk 5 recovers its Plessey Type 195 dunking sonar. Dunking sonar has advantages over expendable sonbuoys, not least being that its depth can be varied.

Above: Operators' console of the RN Type 195 sonar system. Two helicopters using dunking sonar can set up a search pattern that is hard for a submarine to evade.

greater chance of causing critical damage to a submarine than any conventional weapon.

Nuclear warheads are used in anti-submarine torpedoes, depth bombs and stand-off weapons, a typical device being the US air-delivered B57 Mod 1 used by the US and various allied navies. Weighing around 510lb (231kg), the B57 Mod 1 is approximately 119in (302cm) long and 14.75in (37.5cm) in diameter and has a yield reportedly variable between five and ten kilotons. It is carried by US Navy S-3 Viking and P-3 Orion aircraft and SH-3 Sea King helicopters. Other US Navy nuclear weapons with ASW applications are Subroc, which has a W55 warhead with a 1-5kT warhead, and its successor, Sea Lance.

The Soviet Navy has a number of ASW nuclear weapons. The Whiskey class submarine which beached off the Karlskrona naval base in 1981 carried nuclear-armed torpedoes, and presumably Soviet anti-submarine aircraft carry nuclear depth bombs similar to the US B57.

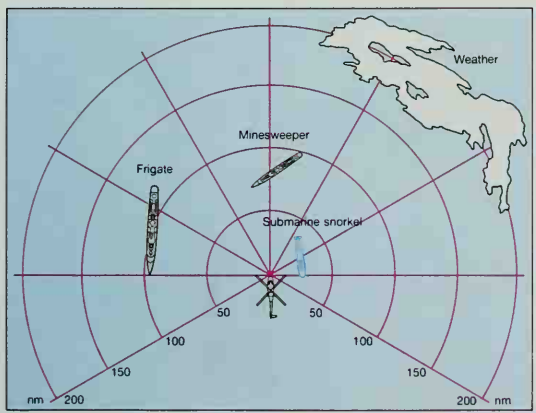
CARRIER-BASED AIRCRAFT

Carrier-based aircraft can take the ASW battle to submarines in any part of the world's oceans, a factor clearly of high importance in the Soviet decision to build their own carrier fleet. ASW tasks are performed by aircraft such as the US Navy's S-3 Viking and the French Alizé, and many types of helicopter, such as the Soviet Ka-32 Helix and the US SH-60B Seahawk.

The principal requirements of an anti-submarine aircraft are the ability to transit rapidly between the aircraft carrier and the patrol line, long endurance on patrol, and the capability to detect, locate, identify and destroy submarine targets. It needs a variety of on-board sensors, including radar (for the detection and classification of surface targets), forward-looking infra-red, magnetic anomaly detectors, sonobuoys and electronic counter-measures equipment. All these sensors, plus inputs from the parent carrier and other ships and aircraft, produce so much information that substantial on-board data processing power is required. Finally, an ideal weapons load would include anti-ship missiles such as Exocet or Harpoon, homing torpedoes, rockets and both conventional and nuclear depth bombs. The only aircraft currently capable of all these tasks is the US Navy's Lockheed S-3 Viking; older aircraft still in service such as the Alizé and S-2 Tracker are much less capable. The Soviet Navy clearly requires a Viking-type aircraft to equip its new 75,000-ton carriers, but no suitable airframe currently exists.

An alternative to the fixed-wing ASW aircraft, albeit one with less range and endurance, is the

OMERA ORB 3211 radar detection ranges



Left: The OMERA ORB 3211 radar is designed for installation in French Aérospatiale SA322 Super Puma helicopters. The detection ranges claimed by the makers range from 200nm for meteorological purposes to 25nm for a submarine snorkel, the latter figure underlining the risks involved in broaching the surface with any part of a submarine.

Below: This French Aéronavale Lynx is equipped with Heracles ORB 31W surveillance radar, Crouzet MAD and Alcatel dunking sonar, and is seen here with a prototype of the Murène antisubmarine torpedo.

helicopter. The earliest ASW anti-submarine helicopters offered no more than a means of delivering torpedoes rapidly in order to counter the speed of nuclear submarines, but as range and payload have increased ASW helicopters have become autonomous weapons systems in their own right. They also have the advantage of bringing an air capability to ships as small as frigates in size. The most advanced airframes currently in service are the US Navy's SH-60B LAMPS III (Light Airborne Multipurpose System), the British Sea King HAS.5 and Lynx HAS.3, and the Soviet Kamov Ka-32 Helix. For the future the most important aircraft currently in development is the European Helicopter Industries EH-101, a British/Italian Sea King replacement which will be equipped with Ferranti Blue Kestrel search radar, Marconi sonar systems, Decca ESM and AQS-81 MAD, all coordinated by a Ferranti data-handling system.

LAND-BASED AIRCRAFT

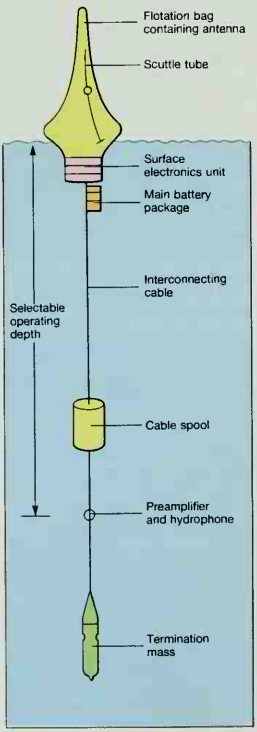
It is essential that there should be a land-based component of maritime-committed airpower. In virtually every country this is provided by naval aviators, except in the United Kingdom where, for historical reasons, the role is carried out by the RAF. The primary roles of land-based aircraft are anti-submarine patrol and maritime strike in support of the naval battle. Land-based aircraft provide effective and virtually all-weather support, but there are limits to their coverage, as was shown in the 1982 South Atlantic War, when the Royal Navy Task Force eventually got beyond the range of its land-based air support on Ascension Island.

The most important of the land-based types are the large ASW aircraft such as the Lockheed P-3 Orion, British Aerospace Nimrod, Dassault-Breguet Atlantic, Shin Meiwa PS-1, Kawasaki P-2J, Ilyushin Il-38 May and Tupolev Tu-20 Bear-F. Only three of these airframes were designed specifically for the ASW mission – the Atlantic, PS-1 and P-2J – another three being particularly successful ASW conversions of relatively unsuccessful commercial airliners, the Nimrod (Comet), P-3 Orion (Electra) and May (Il-18 Coot) while the last, the Bear-F, is a modified strategic bomber. The Japanese PS-1 is an interesting concept, the idea being that it can alight on water for the search and localization phase of its ASW patrol and use its powerful on-board sonar, rather than expend masses of sonar buoys. The idea has not caught on, however; the only other nation to try the idea is China, and the Japanese themselves have returned to land-based ASW aircraft with their large fleet of Kawasaki P-2Js, licence-built, updated versions of the Lockheed P 2 Neptune, and Lockheed P-3 Orions.

These aircraft are used for long-range, long-endurance ocean patrols to detect and track submarines in peacetime and to destroy them in war. In particular, they are required to follow up and classify submarine contacts made by the US Navy's SOSUS and SURTASS surveillance systems and the Soviet equivalents. Their on-board sensors include radar, forward-looking infra-red, low-light television, sophisticated ECM suites and MAD equipment, and they deploy expendable sonobuoys with radio uplinks to give them a sonar capability. Their weapons include torpedoes, conventional and nuclear depth bombs and air-to-surface missiles, making them similar in most

Above: The Il-38 May forms the mainstay of the Soviet fixed-wing antisubmarine aircraft force, and like nearly all such aircraft is a military conversion of a civil airliner. Note the MAD tailboom.

SSQ 904 Jezebel sonobuoy deployment



Below: The standard British sonobuoy, the Jezebel receives sounds generated by submerged submarines and relays them to ASW aircraft. Passive sonobuoys are undetectable by submarines.

Below: An RAF crewman aboard a Nimrod prepares to launch an SSQ 954 DIFAR sonobuoy. This provides target bearing information in addition to the basic signal provided by the Jezebel.

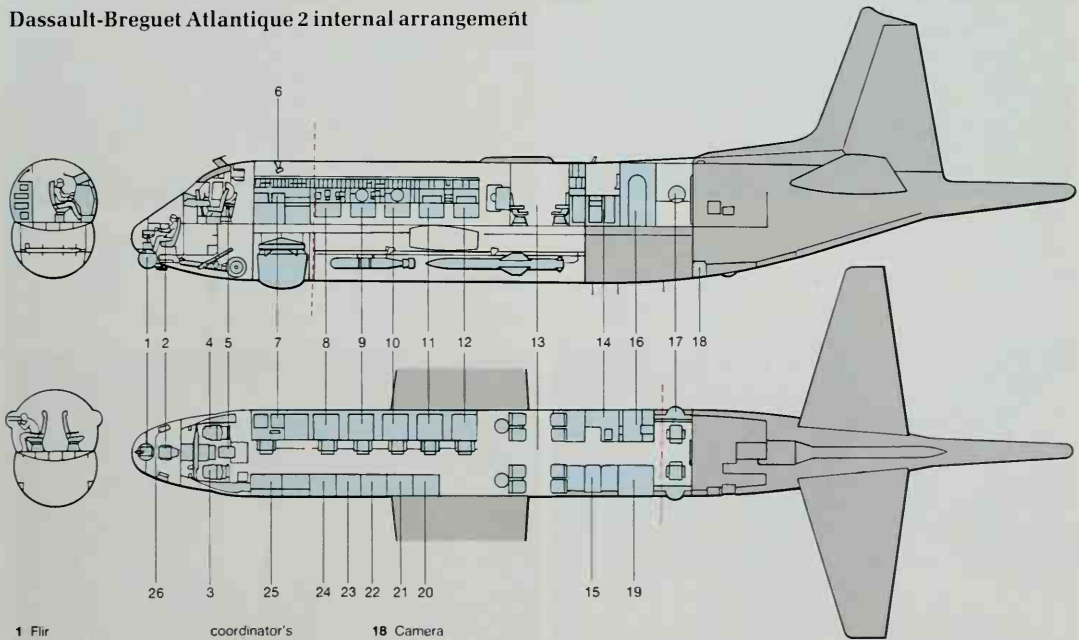
respects to the carrier-based S-3 Viking, but they have much greaater endurance and payload and, with bigger crews, are able to conduct more protracted operations. Published figures for patrol times are 18 hours for the Atlantic, 12 hours for Nimrod and May, and 16 hours for the P-3 Orion. The endurance of the S-3 Viking is nine hours, though exponents of carrier-based airpower argue that because it is already at sea, and therefore much nearer the scene of action, the Viking spends much less time in transit and just as much time, or perhaps even more, on patrol.

Many navies use shore-based helicopters in a short-range ASW role. These are normally simply land-based versions of sea-going anti-submarine helicopters, but the USSR has developed a unique type, the Mi-14 Haze, specifically for the shore-based ASW role.

Another special type developed by the Soviet Union, the over-the-horizon targeting aircraft, provides mid-course guidance for submarine-launched missiles such as the SS-N-3 and SS-N-12; the Tu-95 Bear-D certainly and the Tu-16 Badger-D possibly have such a role. Bear-D has a massive radome in its weapons bay, together with some 40 other antennas, blisters and fairings along its fuselage, wings and tail. Bear-Ds appear to be deployed in pairs in this role, and while they are clearly vital to the missile systems deployed aboard Soviet surface ships their chances of survival and of achieving coordinated timings with submarines seem remote.

Right: The operators' consoles of the Atlantique 2 present information from all the common sensors used to detect submarines. The two sonobuoy operators' positions (foreground) receive hard copy of the information displayed on the screens above them. Next is the tactical coordinator's station, with the radar/IFF operator's position further forward and, finally, the electronic warfare officer/MAD operator's station.

Dassault-Breguet Atlantique 2 internal arrangement



1 Flir
2 Forward observer
3 Pilot
4 Aircraft commander
5 Flight engineer
6 Sextant
7 Radio-navigation station
8 ESM/ECM/MAD station
9 Radar/IFF station
10 Tactical coordinator's station
11 Sonobuoy operator No 1
12 Sonobuoy operator No 2
13 Rest compartment
14 Galley
15 Crew room (table and seats)
16 Lavatories
17 Rear observer
18 Camera
19 Wardrobe
20 Radio equipment
21 Radar/IFF equipment
22 Sonobuoy receiver
23 Computer
24 Navigation equipment
25 Electrical circuits
26 Side-looking camera

Above: The Atlantique 2 is a well laid-out aircraft developed after many years' experience with the earlier Atlantic. Aircrew have to undertake lengthy missions, most of which are flown at low levels in turbulent conditions, typical examples being an eight-hour patrol 600nm from base or five hours at 1,000nm; for such lengthy tasks good facilities for crew comfort are essential.

Accidents and Rescue

The possibility of a submarine being damaged, either by attack in war or by accident at any time is clearly an important consideration both in submarine design and in a submariner's life. Accidents can result from a variety of causes, such as internal explosion, and failure of the hull through exceeding the maximum permissible depth after a loss of control or collision, particularly with surface ships. Since internal bulkheads have far less pressure resistance than the hull a major collapse of the hull at depth would almost certainly be catastrophic and, as was the case with USS *Thresher*, rescue would be pointless as there would be no survivors. Between collapse depth and approximately 650ft (198m), however, rescue by an external vessel is feasible, and at depths of less than 650ft escape without external assistance is possible given suitable equipment.

SUBMARINE LOSSES

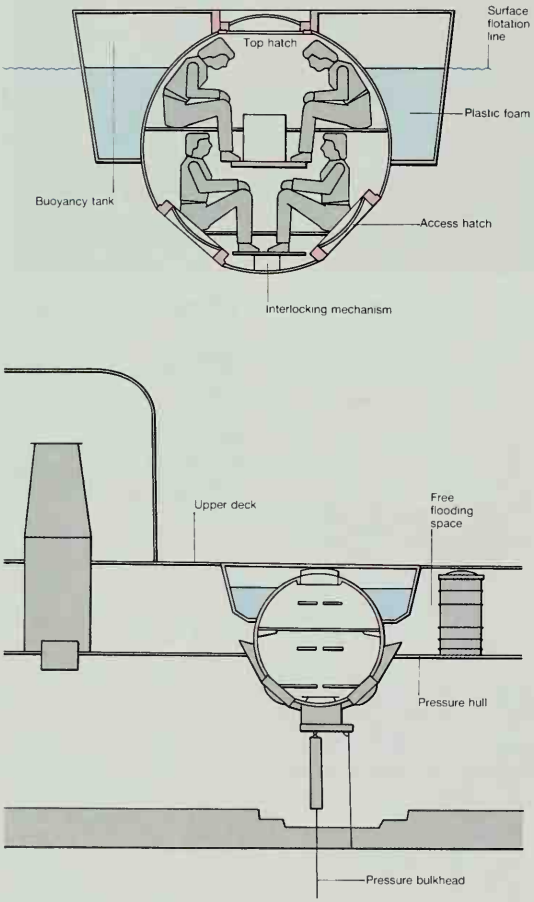
The British have lost only three submarines since the end of World War II: HMS *Truculent* collided with a merchant ship in the Thames estuary in 1950, HMS *Affroy* sank in the English Channel in 1951 and HMS *Sidon* foundered in harbour in 1955, following an internal explosion. The *Truculent* sinking illustrated a particular hazard for submarine escapers in that a number of men used the proper escape apparatus and reached the surface successfully

Above: The Kockums rescue sphere after a successful first ascent from a depth of 260ft (80m). The ventilation mast has been raised and a dinghy has arrived from HDW's tender *Pegasus*.

Below: Following the test the Type 1500 submarine surfaces, with the gap in the upper deck showing where the rescue sphere had been installed. This new system seems to be the most effective yet.

Below: The submarine's crew inside the rescue sphere as seen through the top hatch. There are two decks, with the crew sitting on circular benches. The sphere comes complete with survival kit to sustain the occupants for six days and is equipped with an emergency radio transmitter. The survivors can take it in turts to exercise on the platform of the buoyancy tank.

IKL/HDW rescue sphere



Above: The West German firm of Ingenieurkontor Lubeck (IKL) devised this rescue system, which is built into the Indian Navy's HDW Type 1500 submarines. In an emergency the crew enter the sphere, which is surrounded by a large buoyancy tank and contains enough air to enable 40 occupants to survive for up to 9 hours without fresh air. When the sphere reaches the surface a ventilation mast is raised, and in calm conditions the top hatch can be opened. When rescuers arrive and the crew have been transferred the sphere can either be towed at up to four knots by means of a pre-attached towing line, or hoisted to the deck of a rescue ship.

only to be swept out into the North Sea by the tide.

The US Navy has had two major submarine disasters in the same period. USS *Thresher* (SSN-593) was lost on April 10, 1963, while on deep diving trials following her first major refit: control was lost and she dived suddenly, totally out of control; before the situation could be rectified she had exceeded her crushing depth and the hull collapsed, primarily as a result of weld failure. The hull broke up and came to rest on the bottom at a depth of some 8,400ft (2,560m), but there has never been any trace of radioactive leaks. Her crew of 108 men plus four naval officers and 17 civilians on board for the trials were lost.

In a second disaster USS *Scorpion* (SSN-589) was lost on about May 27, 1968, along with her entire crew of 99 men. She was some 200nm (370km) southwest of the Azores, travelling from the Mediterranean to Norfolk, Virginia, on a routine crossing of the Atlantic. Her loss illustrated the submariners' perpetual communications problem, since it was some days before it was realised ashore that she was overdue. *Scorpion* lies at a depth of some 10,000ft (3,048m), but again there has never been any abnormal radiation.

The Soviet Navy has also suffered major disasters, though it is doubtful whether full details will ever be published, even if they are known, in the West. It is believed that several Foxtrot class submarines have been lost over the years; surprisingly, no other diesel-electric patrol boat is known to have sunk, but one diesel-electric ballistic missile submarine was lost in the Pacific in April 1968. The Golf-II SSB was carrying her usual load of three SS-N-5 SLBMs and the American CIA mounted a highly ambitious clandestine operation to recover her, using the deep-sea recovery ship *Glomor Explorer*. As far as is known the forepart of the sunken submarine was recovered in 1974, but whether this included any missiles has never been made public.

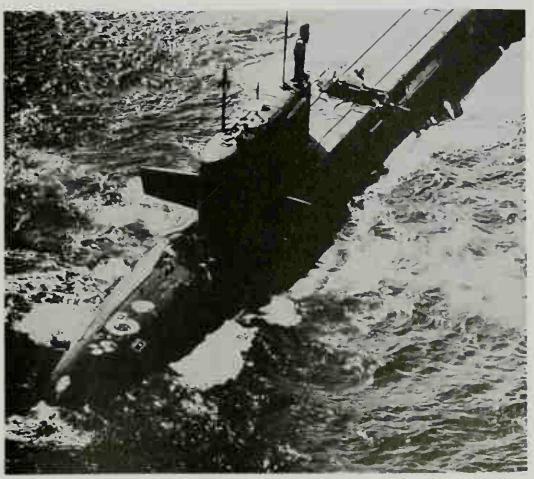
Of the Soviet nuclear submarines, one November class boat was lost off Finisterre in April 1970: most if not all the crew were rescued and no nuclear contamination has ever been detected in the area. Other Novembers have been seen in difficulty on the surface, and have had to be towed to Soviet ports for repair, and one Charlie class SSGN sank in the Pacific near Kamchatka in June 1983 for reasons never made public. She was later salvaged by a Soviet recovery ship.

The only French postwar losses have been three Daphné class conventional submarines. The first, *Minerve*, was lost without trace in the Mediterranean on January 27, 1968, and *Eurydice* disappeared, again without trace, off Toulon on March 4, 1970. These losses caused considerable anxiety about the Daphné class, which was doing well in the export markets;

SOVIET NAVY SUBMARINE ACCIDENTS

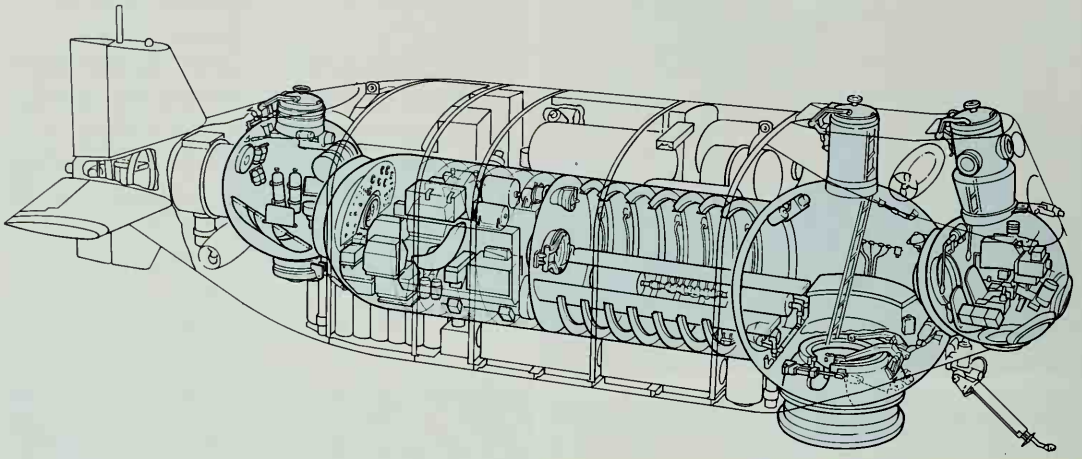
1966	A radiation leak in a nuclear submarine near Polynarny, close to the submarine base in the Kola Inlet, reportedly caused the crew to panic and there were some deaths. (Jane's Defence Weekly, Jan 19, 1985)
1966-68	A fire on board a Soviet nuclear submarine transiting under the Arctic ice cap caused several casualties. (ibid)
1968	A Golf II SSB was lost in the Pacific: the CIA recovered at least part of the submarine in a clandestine operation in 1974, using the specially fitted-out *Glomor Explorer*.
1970	A November class SSN caught fire in the Atlantic. According to US sources the captain ordered his crew to abandon ship, but they refused; the fire then spread towards the reactor and the submarine was scuttled with great loss of life. (JDW)
February 1972	A Hotel class SSBN surfaced in the North Atlantic off the Newfoundland coast in serious trouble. (JDW)
December 1972	A nuclear weapon accident on board an SSBN off the US coast is believed to have involved a radiation leak from a nuclear-armed torpedo of the type designed to attack US harbour installations. Several men died and the majority of crew suffered some form of radiation sickness. (JDW)
October 1976	A nuclear submarine in the Atlantic suffered a fire, with three officers reported killed. (JDW)
1977	Twelve officers were evacuated from a nuclear submarine in mid-Atlantic and flown to Leningrad as a result of a medical emergency involving exposure to radiation. (JDW)
1977	A fire on board a nuclear submarine may have been caused by failure of an outdated reactor. (JDW)
September 1981	A nuclear submarine in the Baltic had an emergency and was towed to Soviet waters at night. Several sailors died from "severe nuclear poisoning". (JDW op. cit.)
June 1983	A Charlie I or II was lost off Kamchatka in the Pacific; her hulk was later recovered by the Soviet Navy.
November 1983	A Victor III was forced to surface about 470 miles off the South Carolina coast (in the so-called Bermuda Triangle) after fouling the towing cable of a US Navy frigate's variable-depth sonar. She wallowed on the surface for some time while a Soviet AGI stood by until a salvage vessel arrived from Cuba. (TIME, November 14, 1983)
June 1984	An Echo II which fouled her propellers with a wire some 500nm north-northeast of the Shetland Islands was spotted on the surface trying to clear them.
June 1984	A Whiskey class conventional submarine was caught in the nets of the Norwegian trawler Bentin. A Norwegian coastguard cutter dropped hand grenades to signal the submarine to come to the surface, which she did after a further two hours.
June 1985	A Victor I SSN transiting the Straits of Gibraltar collided with a Soviet tanker, possibly while trying to hide in the tanker's noise shadow. (The combination of warm and cold layer in the Straits make it difficult to maintain a set depth, especially where a sudden thermal gradient makes a submarine porpoise.)
September 18, 1985	A fire on board a Golf II SSB off the Japanese coast was probably caused by an electrical overload after the boat was caught in a Japanese trawler's nets; smoke was seen to be coming from missile hatches in the sail. The boat was given assistance by Soviet minesweepers and an oiler and eventually limped back to Vladivostok.
Octobe. 1986	Following a fire in one of the SS-N-6 Sawfly missiles on board, a Yankee class SSBN was forced to surface some 600nm north of Bermuda and 760nm from New York. She was taken under tow by a Soviet merchantman, but later sank. Three crewmen died and several were injured.

Above: Following an August 28, 1976, collision with USS *Voge* (FF 1047) a Soviet Echo II SSGN wallows with her sail barely awash. Such collisions are rare.



Below: Soviet Yankee class SSBN on the surface in October 1986, after a fire in one of her SS-N-6 missiles. On patrol off the US east coast, she sank after limping for several days on the surface.

Kockums URF submarine rescue vehicle



Above: The Swedish URF undersea rescue vehicle comprises a pressure hull (blue) surrounded by an outer casing. Two controllers sit in the operators' compartment forward; aft of this are, in turn, the rescue compartment, an auxiliaries compartment and the diving compartment.

then, in 1971, Flore's snorkel system sprang a leak due to a faulty valve, but on this occasion an alert captain was able to take immediate remedial action and save his boat. Finally, on November 11, 1972, Sirène sprang a leak and sank, but she was later recovered and recommissioned and, presumably as a result of at last being able to identify the problem, no other members of the class have been lost. On the other hand, nor were any more export orders received.

ESCAPE TECHNIQUES

Escape from a sunken submarine is feasible in many circumstances, the most elementary being for the survivors of an accident to escape through specially designed hatches using various types of escape gear. British submarines have two single escape towers, one at each end of the boat, and each man has a hooded immersion suit, a system which has been proved down to 600ft (183m). The suit has a hood containing trapped air for the survivor to breathe during the ascent, and protects him from hostile conditions on the surface; in the escape tower the survivor plugs a built-in connector into a socket on the built-in breathing system, which provides pure air to inflate the lifejacket and fill the hood, and within about 16 seconds he is ready to leave. Sea pressure is then applied, the hatch is opened and the man immediately exits, ascending at 8ft/sec (2.4m/sec) and breathing normally as he does so. Once on the surface he unzips the hood, inflates the double-skinned survival suit and awaits the arrival of his rescuers.

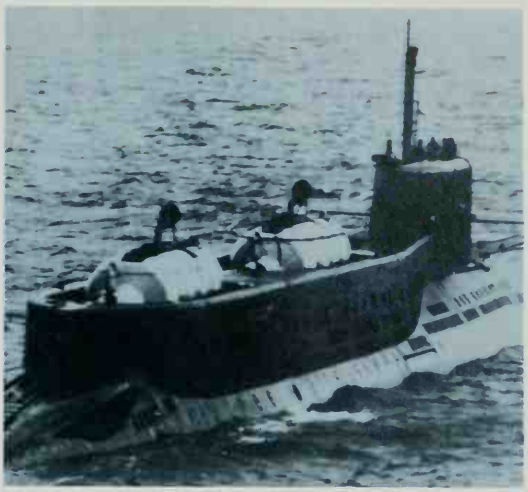
At depths greater than 650ft a rescue vehicle is essential and several have been developed. The US Navy Deep Submergence Rescue Vehicle (DSRV) is, in effect, a small, air- and road-mobile submarine of which it was initially planned to build 12, each capable of carrying 12 survivors, but in the event just two, each capable of transporting four crewmen and 24 survivors, were constructed. They became fully operational in 1977 and have been tested in use with both US and British submarines; capable of operating at a maximum depth of 4,921ft (1,500m), the DSRV can withstand pressures equivalent to 9,022ft (1,750m). A normal propeller is capable of moving the craft at a maximum of five knots and two thrusters are fitted to manoeuvre it close alongside a sunken submarine. The vessel consists of two HY-240 steel spheres surrounded by a fibreglass hull, and is designed to be loaded into a USAF C-141 StarLifter, while the road transporter and additional support equipment travel in a second C-141. The DSRVs are taken to the scene of the rescue either on a special cradle mounted on the after deck of a suitably modified submarine or one of the two Pigeon class catamaran submarine rescue ships.

The Soviet Navy has arrived at a different and unusual answer to the same problem. It also has submersible rescue vehicles, each some 36ft (11m) long and with a shrouded propeller, but they are transported by the specially constructed India class submarines. These boats, of 4,800 tons submerged displacement, have large wells on their after casings, in which sit two of the submersibles, and they usually travel on the surface, submerging only when in the immediate vicinity of the sunken submarine. There are two India class submarines, one with the Pacific

Above: Built of HY 130 steel, the URF can operate at a maximum depth of 1,510ft (460m) – collapse depth is 2,953ft (900m) – and it can be docked with a submarine at angles of up to 45°. The vessel is moved by road on a low-loader then towed, on the surface or submerged, to an accident scene.

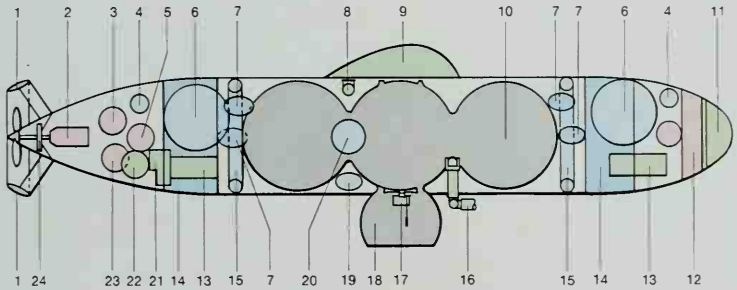
Below: Underwater view of the US Navy Deep Submergence Rescue Vehicle *Mystic* (DSRV-1), which is designed to operate at a maximum depth of 4,921ft (1,500m), with a collapse depth of 9,022ft (2,750m). Clearly seen here are the headlight, the duct for the bow thruster and the transfer skirt.

Above: *Avolon* (DSRV-2) mounted on the stern of the Royal Navy submarine HMS *Repulse* during an interoperability exercise in the Firth of Clyde in 1979. The exercise involved the transfer of 10 men and a quantity of stores from one submerged submarine to another. Twelve such vessels were planned, but only two were built.



Above: The Soviet Navy deploys two India class rescue submarines, one each in the Pacific and Northern Fleets. Designed to cruise on the surface, the Indias have large dorsal docking wells which carry two rescue submersibles, one approximately 40ft (12.1m) and the other about 37ft (11.3m) long.

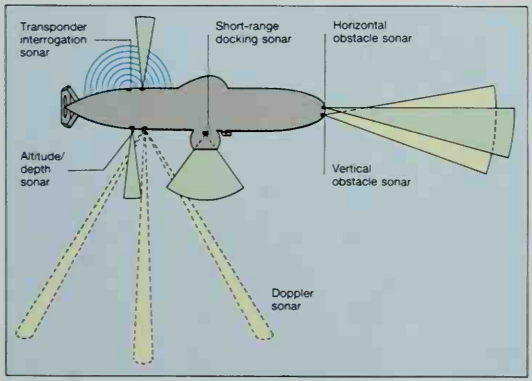
DSRV general arrangement



1 Tilting shroud
2 Main propulsion motor
3 Thruster controllers
4 Trim tanks
5 Thruster ducts
6 Transfer tanks
7 Variable ballast tanks
8 List pump
9 Access hatch canopy
10 Pressure capsule
11 Sonar dome
12 Forward thruster ducts
13 Battery banks
14 Ballast tanks
15 Toroidal tanks
16 Manipulator
17 Hauldown winch
18 Transfer skirt
19 Mercury tank
20 List tank
21 Hydraulic power pack
22 High-pressure air
23 Hydraulic and propulsion controllers
24 Shroud gimbal

Pressure capsule
Other tanks
Ballast tanks
Propulsion
Miscellaneous

DSRV sensors



Above: The US Navy's DSRV is based on a three-sphere pressure capsule constructed of HY 140 steel which can accommodate the four-man crew and up to 24 survivors. The DSRV can be airlifted by Lockheed C-141 StarLifter, is road-mobile on a low-loader, and can be carried at up to 15 knots by any submarine with suitable mountings.

Left: Getting to the scene of an accident is one thing; finding a disabled submarine in the murky depths of the ocean is another. To cope with the hostile environment the DSRV is provided with a comprehensive range of sonars as shown, while optical systems include six television cameras, a 35mm still camera, flood and strobe lights and viewing ports.

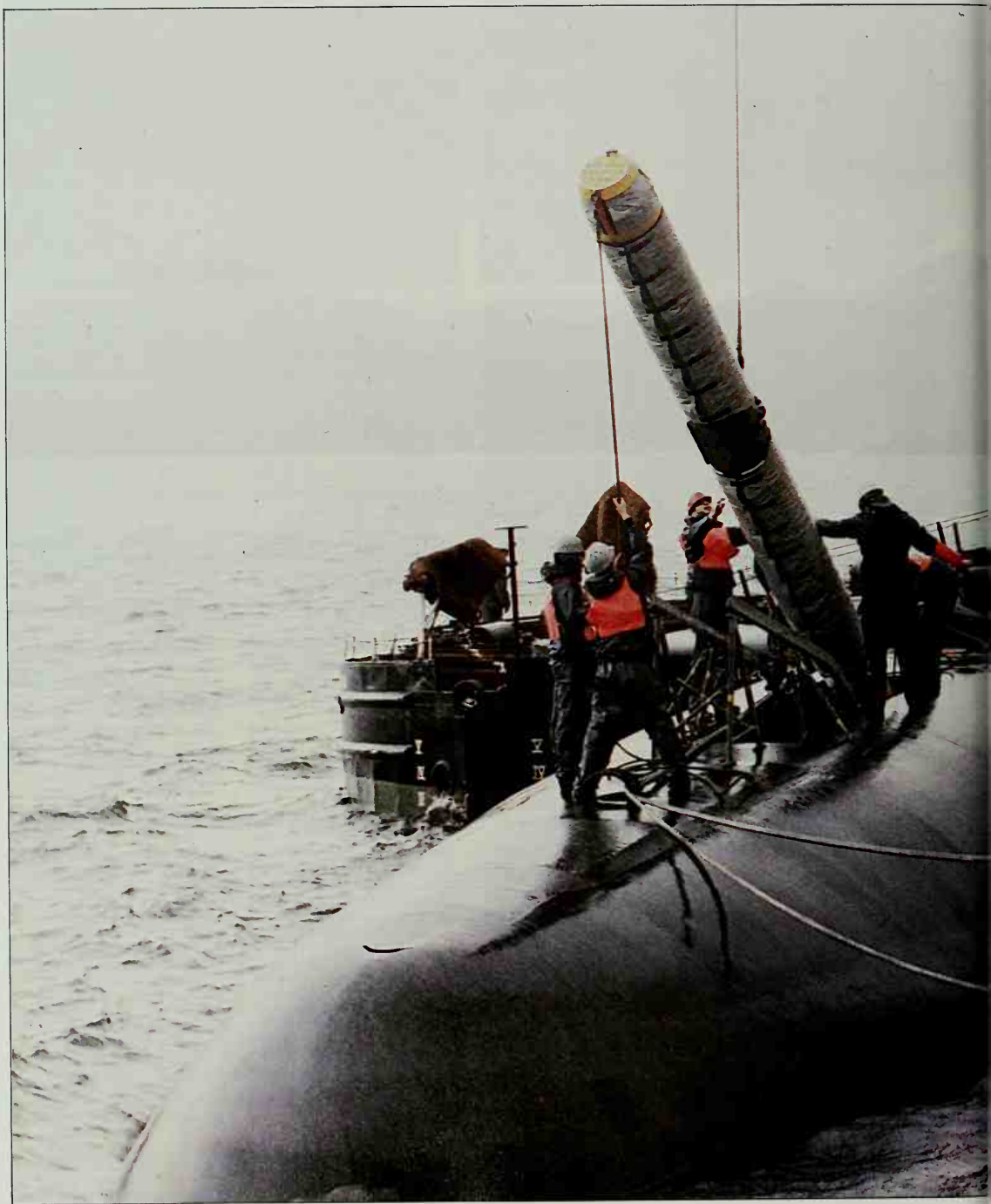
Fleet and the other with the Northern Fleet.

The Soviet Navy also has a number of submarine rescue ships, including the 22,500-ton *Elbrus*, the only ship of her type in the world with an ice-breaking capability, presumably to support the latest SSBNs. Two submersibles are carried abaft the funnel and launched by gantries. The single 10,000-ton Nera class, eight 3,200-ton Prut class and 11 930-ton Valday class rescue ships have equipment and capabilities commensurate with their size.

Other navies are less well provided for. The Italian Navy has one salvage ship, the *Anteo* of 3,780 tons, which carries US-style submarine rescue equipment, including a McCann rescue bell. She also carries a 22-ton MSM-1/S submersible named *Usel*, which has a maximum operating depth of 1,970ft (600m). The French Navy has a similar ship, the 1,150-ton *Triton*, which is intended primarily for underwater research but has a rescue capability; her equipment includes a 13.5-ton tethered bell which can be used down to 820ft (250m) and a two-man submarine, the 16-ton *Griffon*, which can dive to a maximum of 2,000ft (600m). Japan has a rescue ship, the *Chiyoda* (4,450 tons), whose Japanese-designed, Kawasaki-built deep-submergence rescue vehicle is 39.4ft (12m) long and has a displacement of 40 tons.

Sweden, whose rescue missions are unlikely to be outside the relatively shallow Baltic, has a submarine rescue ship, the *Belos* (965 tons), which supports the 50-ton URF rescue submersible. The latter, constructed of HY-130 steel, has a maximum operating depth of 1,510ft (460m) and a collapse depth of 2,952ft (900m).

Submarines and their



Weapons

John Jordan

Below: A heavyweight torpedo is manoeovred into position for embarkation through the weapons hatch of the Valiant class attack submarine HMS *Conqueror*.

Introduction

The following pages provide illustrations of the major classes of submarine currently in service, together with technical data and construction details. A large part of the text is devoted to the historical background of the class and to the prominent technical aspects of the design; other sections detail the various weapons carried by the submarines since their completion, and the location, designation and capabilities of the sensor arrays.

Although the number of submarines completed to each design is given, the names of individual units have been omitted. Two pages have been allocated to each class in order to provide consistency in layout and coverage, and the inclusion of names would have severely restricted the description of aspects of the design in the case of the larger classes, such as the US Navy's Los Angeles and Sturgeon.
As these types are among the most important designs dealt with it was felt that this would create a serious imbalance.

In a book such as this, it is never easy to decide which classes should be included and which should be omitted. As regards submarines the decision is made all the more difficult by the imbalance of construction, with small nations such as the Netherlands and Sweden building a succession of interesting designs in small numbers, while the United States and the Soviet Union build their own designs in classes of 30, 40 or 50. The author felt it was important to include any submarine type built in large numbers, but has attempted to compensate for this by discussing the design aspects of smaller classes which had to be omitted in the entries for other classes selected as representative of that country's construction. Thus Sweden's Sjöormen and Västergotland classes are covered in the entry for the Näcken class.

The final list of entries reveals the extent of Soviet submarine construction since World War II, with more than a third of the following spreads devoted to submarine types of Soviet design. In modern times no other country, even the United States, has ever had more than two types of submarine under construction simultaneously, yet in 1986 no fewer than seven different types, all of recent design, were under construction for the Soviet Navy.

The predominance of Soviet entries has created a number of problems both for the author and, more particularly, for the artists. We only ever see the uppermost part of a submarine's hull: the torpedo tubes, the propellers and the after control surfaces are beneath the water, while the torpedoes and missiles are carried within the hull and there are rarely tell-tale bulges to help us determine the configuration of the major sonars.

All submarines are designed for covert operations, and even the Western navies are less than forthcoming about major aspects of their submarine designs, particularly with regard to the precise designation, configuration and performance of sonar arrays. The Soviets guard their military secrets even more jealously, and the covert nature of submarine operations greatly facilitates their task: the only published photographs of Soviet submarines in dry dock depict elderly units of the Whiskey and Romeo classes, while data on Soviet submarine weapon systems and sonars comes exclusively from Western intelligence sources, is rarely complete, and is often unreliable and subject to correction as time passes.

Above: The test launch of a UGM-84 Harpoon missile from a US submarine. Underwater-launched cruise missiles make it possible for the submarine to engage its targets at greater range.

Right: The Dutch submarine *Dolfijn*, one of the most innovative postwar designs, introduced the multi-pressure hull concept to modern submarine construction.

Clearly there are serious implications for a book of this type. All drawings depicting the underwater configuration of Soviet submarines must be regarded as provisional, and the weapons depicted are those with which particular classes are credited by the major Western reference sources. The configurations of weapons such as the SS-N-3A anti-ship missile and the M-57 torpedo are based on published photographs, but those of more recent weapons must again be regarded as provisional. This is particularly true of the SS-N-15 and SS-N-16 anti-submarine missiles, whose configurations have been based of necessty on those of Western submarine-launched missiles of similar conception.

To attempt a serious comparison with contemporary Western submarines is clearly a major undertaking. Nevertheless, the author has made extensive use of the available reference sources in order to establish a consistent and logical overview of Soviet submarine development and weapon capabilities. The inclusion of all the weapon systems with which Soviet submarines are generally credited was considered essential to provide a complete picture, and these considerations largely outweighed any concern regarding visual accuracy.

Few submarine designs in this section of the book can be regarded as truly international. Drawings of submarines such as the German Type 209, which was designed for export, depict individual units in service with specific countries, together with their associated weapon systems, and any differences in the weapon and sensor outfits of boats in service with other countries are detailed in the text.

Left: A US Navy artist's impression of the Soviet Navy's Oscar-class cruise missile submarine (SSGN) published while the first unit was still fitting out at Severodvinsk. Although inaccurate in some respects, the drawing gets most of the detail right, including the number and position of the missile hatches, and the VLF buoy housing immediately abaft the fin.

Below: The real thing! The first unit of the Oscar class, seen here in northern waters shortly after completion. The Soviet Navy has apparently experienced some problems with the adhesion of the rubberized tiles designed to reduce the sonar signature of its latest submarines. A number of those applied to the curved sections of the hull casing are missing in this photograph.

Agosta class

Origin: France, first unit completed 1964
Type: Attack submarine, diesel-powered (SS)
Displacement: 1,490 tons surfaced; 1,740 tons submerged
Dimensions: Length 222ft (67.6m); beam 22ft (6.8m); draught 18ft (5.5m)
Propulsion: Diesel-electric drive on one shaft; two SEMT-Pielstick 16 PA 4 185 diesel generators, each 1,270bhp; one Jeumont-Schneider electric motor; 2,540bhp for 12.5kt surfaced, 2,990hp for 17.5kt submerged (see remarks)
Complement: 54
Background: With the loss of French Indochina in the early 1950s long range, which had been a primary requirement for the postwar Narval class, became less important. On the other hand, the Daphné class had proved to be on the small side for French maritime commitments, which by the late 1960s included a major presence in the Indian Ocean. Moreover, since the Daphnés had been designed there had been important new developments in submarine technology: the 'Albacore' hull-form had revolutionised underwater performance, while Modern torpedoes with sophisticated homing devices allied to computerized fire control made large salvos unnecessary, so fewer torpedo tubes were needed. The four attack submarines of the Agosta class, laid down between 1972 and 1974, were therefore not only significantly larger than the Daphnés, but of a completely new design.
Design: Double-hull construction was retained for these submarines, the space between the two hulls being used for ballast and fuel tanks, and for the sensing heads of much of the acoustic equipment. As with the earlier French designs, all deck protrusions retract to ensure a smooth waterflow. The pressure hull comprises a cylinder with cones fore and aft and is enclosed by a cylindrical outer casing which terminates in an oval-shaped bow housing the principal active and passive sonar arrays. In order to save weight, extensive use of plastics was made in the construction of the fin. The latter is positioned well forward, so that all the accommodation and messing spaces for the crew are grouped together abaft the control/attack centre. Beneath the control centre and the accommodation spaces are two battery compartments, each housing 160 Type N battery cells. This is double the number of cells installed in earlier French submarines, and gives the Agostas exceptionally good underwater endurance. The diesel-electric propulsion plant allows for continuity of speed over the full power range. The main electric motor can produce 3,475kW (4,725hp) for short periods, boosting the maximum underwater speed to 20.5 knots. A separate creep motor can propel the submarine at 1.5 knots during silent patrol operations. It uses little power, enabling the submarine to remain submerged for long periods. The single five-bladed propeller is located

Below: ***Hurmat***, **the second of two Agosta class submarines in service with the Pakistani Navy. Originally ordered by South Africa, they were sold to Pakistan while under construction in 1977 as a result of a United Nations arms embargo. They were built by Digeon, Nantes, and entered service in 1979-80.**

Above: *Galerna*, the first of four Agostas built under licence in Spanish shipyards. Two were completed in 1983, and a further pair in 1985. French technical assistance had previously been provided for the construction of four Daphné class boats also by Bazán, Cartagena.

abaft modern cruciform control surfaces. The forward hydroplanes are mounted close to the bow.

Armament: The traditional French 21.7in (550mm) calibre was adopted for the four bow tubes of the Agostas to enable them to fire existing torpedoes. However, the tubes were designed to handle both 21.7in (550mm) and more modern 21in (533mm) torpedoes. The L 5 21in (533mm) antisubmarine torpedo already well established as a surface-launched weapon, is free-running, employs active acoustic homing, has a maximum speed of 35 knots and a maximum range of 7,700yds (7,000m). It is now being superseded by the F 17, a wire-guided torpedo with electric propulsion and passive acoustic homing. The Mod.1 variant is an anti-ship weapon but an antisubmarine variant, designated the F 17P, has recently entered service. The Agostas currently carry a total of 20 torpedoes of both the L 5 Mod.3 and the F 17 types. Bévéziers conducted trials of the SM 39 Exocet submarine-launched anti-ship missile (see Rubis), and it is envisaged that the SM 39 will eventually be in service with all four boats of the class.

Electronics: The Agostas have a similar sonar outfit to the modernised boats of the Daphné class. Both DUUA 1 and DUUA 2 active/passive sonars are fitted, together with a DSUV 22 circular passive hydrophone array. There is a DUUX 2 passive ranging sonar, and DUUG/AUUD sonar intercept equipment. Torpedo fire control is provided by the DLT D-3 FC system linked to an Iris 35M computer. The system comprises a display of the tactical situation, based on inputs from the various sensors, a targeting display and a weapons control console. Simultaneous control of several torpedoes is possible.

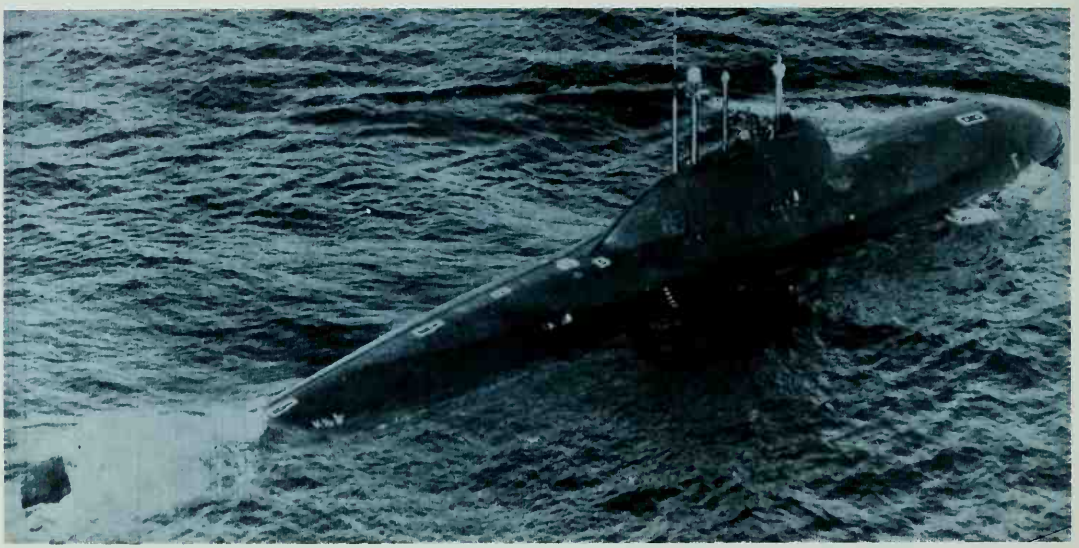
Mast-mounted sensors include search and attack periscopes, a DRUA-33 surveillance radar, and ARUR and ARUD ESM intercept aerials.

Construction: Four submarines of the Agosta class were completed for the Marine Nationale between 1977 and 1978 and a further four were built under licence in Spain with French technical assistance between 1977 and 1985. Two Agostas were ordered from French shipyards by South Africa, but a United Nations embargo prevented these from being delivered, and they were re-sold to Pakistan. An order for a further two units from Spanish shipyards has yet to be confirmed.

Below: The Agostas have four bow tubes of 21.7in (550mm) diameter capable of accommodating older model torpedoes and more modern 21in (533mm) types. The current outfit consists of L 5 Mod 3 free-running anti-submarine torpedoes (1) and F 17 Mod 1 (2) wire-guided anti-ship torpedoes. Both types are now being superseded by the F 17 Mod 2, which has a dual seeker. The class is now being retro-fitted with the necessary fire control electronics for the SM 39 Exocet anti-ship missile (3). Weapons capacity is 20 torpedoes or missiles. Three TSM 3510 mines (4) can be carried in place of one torpedo.

Alfa class

Origin: USSR, first unit completed 1972
Type: Attack submarine, nuclear-powered (SSN)
Displacement: 2,900 tons surfaced; 3,680 tons submerged
Dimensions: Length 267ft (81.4m); beam 31ft (9.5m); draught 23ft (7m)
Propulsion: One liquid-metal reactor with turbo-electric drive on one shaft; two steam turbo-alternators, one motor; 47,000hp for 42-43kt max
Complement: 45
Background: Ironically, the original impetus for the development of the Alfa may have been provided by US official policy statements dating from the late 1950s to the effect that within the decade submarines would attain speeds of 45 knots and diving depths of 3,000ft (900m). The Soviets undoubtedly saw a use for such a submarine as a fast interceptor to be used against surface forces and hostile submarines detected by their ocean surveillance system. If the submarine were operated in a more offensive role, high underwater speed combined with a deep-diving capability would enable the submarine to evade Western antisubmarine defences by passing beneath them. Surface-launched ASW weapons such as homing torpedoes would take such a long time to reach the operating depth of the submarine that the latter would by then have passed out of range of the acoustic homing device. The decision to build the Alfa was followed by a prolonged development period during which the Soviets were always operating on the outer edge of technology. The development of a reactor employing liquid metal as a coolant cannot have been easy, to judge from US Navy experience with the submarine *Seawolf* (SSN-575) in the late 1950s: the *Seawolf* reactor was abandoned as unreliable within two years, and replaced by a conventional pressurized water-cooled model. The adoption of titanium for the Alfa's pressure hull in order to increase diving depth also posed serious problems. Titanium is much lighter than steel and has greater tensile strength, but it is difficult to roll and bend, and special welding processes had to be introduced. The prototype boat, completed in 1972, appears to have experienced serious cracking of



Above: The Alfa is one of the world's most remarkable submarines. The hull is constructed not of steel but of lightweight titanium, giving the Alfa an operating depth estimated at around 900m (3,000ft) while the unmanned propulsion plant, which is powered by a liquid-metal reactor, produces a maximum underwater speed in excess of 40 knots. However, slow series production was terminated after six production boats had been completed.

the welded joins, and following extensive trials in the Baltic had to be abandoned; she was broken up in situ in 1974. However, the Soviets persisted with the design and eventually resolved many of the associated problems, and series production began in the mid-1970s, the first boat being completed in 1979.

Design: The Alfa has a single reactor which employs a lead-bizmuth mixture as coolant. This results in a particularly compact propulsion plant, as only the reactor itself needs to be located within the containment shield. The adoption of a liquid-metal coolant also raises the temperature in the steam generator, enabling exceptionally high horsepower figures to be achieved for a reactor of moderate size. The propulsion machinery of the Alfa is highly automated, and it is reported that the engine room is entirely unmanned, but safety and accessibility standards are almost certainly far lower than would be permitted in the West. It is also reported that these submarines are exceptionally noisy at speed. This is hardly surprising given a combination of small submarine size and high power output, which almost certainly precluded 'rafting' or other methods of insulating machinery noise. Unlike other Soviet submarines, the Alfa appears to be of single hull construction, with a particularly smooth transition between the casing and the base of the streamlined fin. The single shaft is fitted with a seven-bladed propeller and there are conventional cruciform tail surfaces.

Armament: The Alfa is fitted with six bow tubes of standard 21in (533mm) diameter. These can fire conventional anti-ship or antisubmarine torpedoes, and the Alfa is probably also equipped to fire the SS-N-15 nuclear-tipped antisubmarine missile. There is no evidence to suggest that even the production boats are fitted with the larger 26in (650mm) tube. The distance between the bow and the fin is comparatively short, and this would appear to preclude installation of the larger tube and accommodation of the SS-N-16 missile together with its associated fire control consoles. There is undoubtedly less space available for torpedo stowage than on other contemporary Soviet SSNs, and a maximum figure of about 12 torpedoes/missiles seems likely.

Electronics: The Alfa has an active/passive bow sonar which is probably located above the torpedo tubes. The outfit of sensor masts is broadly similar to that of the Victor-class SSN and the Charlie-class SSGN: search and attack periscopes, Snoop Head/Bald Head combined surface surveillance/ESM, Park Lamp VLF reception, and aerials for HF and VHF communications. There are no hatches for VLF buoys, and no other visible towed arrays either for communications or for passive acoustic detection.

Construction: There is some disagreement about completion dates for these submarines, particularly for the prototype boat. The latter was built by the Sudomekh Shipyard, Leningrad, and is stated by some sources to have been completed as early as 1968. The six production boats were completed between 1979 and 1983 at Leningrad and Severodvinsk. Construction has now been terminated in favour of a larger titanium-hulled submarine, the Mike.

Left: The Alfa is credited with six bow tubes of standard 21in (533mm) diameter. These can handle long free-running anti-ship torpedoes with alternative conventional HE or nuclear warheads (1), and acoustic-homing antisubmarine torpedoes (2), two mines (3) can be carried in place of a single torpedo. It is thought that the Alfa is also equipped to fire the SS-N-15 nuclear-tipped antisubmarine missile (4), but there is no evidence to suggest that the type is fitted with the large-diameter 26in (650mm) tube.

Charlie class

Origin: USSR, first unit completed 1967
Type: Cruise missile submarine, nuclear-powered (SSGN)
Displacement: Charlie I: 4,000 tons surfaced; 4,800 tons submerged
Charlie II: 4,500 tons surfaced; 5,500 tons submerged
Dimensions: Charlie I: length 312ft (95m); beam 33ft (10m); draught 26ft (8m)
Charlie II: length 335ft (102m); beam and draught as Charlie I
Propulsion: One pressurized water-cooled reactor driving geared steam turbines; one shaft; 15,000shp for 24kt max
Complement: 90
Background: The development of a short-range, active radar homing missile which could be fired from underwater, the SS-N-7, promised to make the anti-shipping torpedo obsolete. Submarines thus equipped would be able to approach their targets undetected, launch their missiles outside the effective sonar range of the escorts, and make their escape without exposing themselves to enemy countermeasures. The Charlie is therefore the true successor of the torpedo-armed November class, the last unit of which was completed in the same year that the first of the new SSGNs was laid down. The threat posed by the pop-up launch mode of the SS-N-7 missile was taken very seriously by the US Navy, which was compelled to accelerate the development of close-in anti-missile weapons and electronic countermeasures (ECM). One of the primary missions of the US 'fleet submarines' of the Los Angeles class (qv) was to clear a path ahead of the carrier battle groups, where Soviet submarines might be lying in wait. These countermeasures appear to have influenced the Soviet Navy into a phasing out of the Charlie programme in the late 1970s.
Design: The Charlie belongs to the second generation of Soviet nuclear-powered submarines. The first of the class entered service in 1968, the year in which the first unit of the Victor class commissioned, and despite fundamental disparities in mission between the Victor and the Charlie, there are a number of striking similarities between the two designs. Length and beam are virtually identical, and the

Above: The broad bow of the Charlie houses eight vertical launch tubes for the SS-N-7 anti-ship missile. The SS-N-7 was the first Soviet anti-ship missile which could be fired from underwater: earlier Soviet SSGNs had to surface in order to launch their missiles, and were therefore vulnerable to attack by hostile aircraft. The submarine depicted is a Charlie I.

Below: The main armament of the Charlie I comprises eight SS-N-7 cruise missiles, which are fired from vertical launch tubes set into the bow. The Charlie II is thought to carry the SS-N-9 missile (1), which has longer range. The six 21in (533mm) bow torpedo tubes can fire a variety of weapons. In the Charlie II these include the SS-N-15 nuclear-tipped antisubmarine missile (2), plus a small number of antiship torpedoes (3).

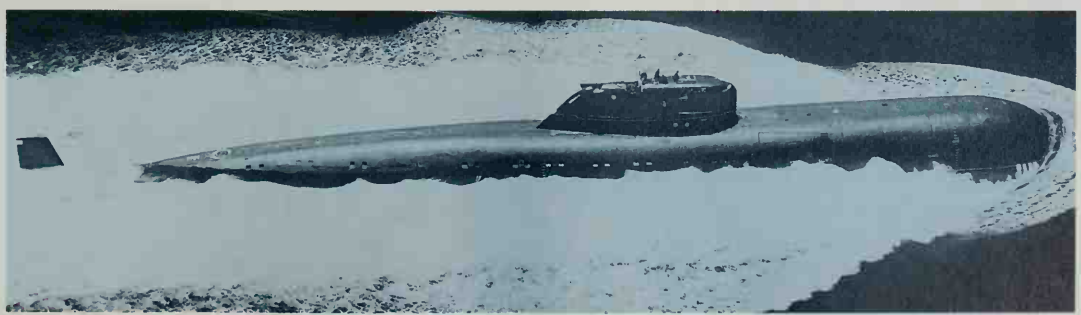
propulsion system employs similar technology, with a single shaft driving a single, five-bladed propeller. They can be distinguished by the shape of the fin, the forward edge of which is angled in the Victor but vertical in the Charlie. The latter feature appears to have been not entirely successful, as a collar-shaped fairing is now being fitted at the base of the fin to improve hydrodynamic performance. The Charlie has cruciform after control surfaces, and retractable forward hydroplanes are mounted on the hull immediately abaft the missile tubes. The eight launch tubes for the SS-N-7 missile are located in the bow section between the inner pressure cylinder and the outer hull casing. They are covered by large square hatches some 14ft (4.25m) long, four on either side. The later variant, the Charlie II, which first appeared in 1973, is some 23ft (7m) longer than the Charlie I. An additional hull section has been inserted between the fin and the bow. The missile tubes are slightly farther aft, but contrary to early reports there has been no increase in their number, which remains at eight. The configuration of the fin and the after section of the later boats remains unchanged.

Armament: The SS-N-7 Siren is a conventional aeroplane-shaped missile with a length of about 23ft (7m). It employs solid-fuel propulsion, and has an estimated range of 30-35nm (55-64km). It can carry a nuclear or conventional warhead weighing approximately 1,100lb (500kg), making it particularly effective against large surface warships. It is reported that the Charlie II may carry the more advanced SS-N-9 missile, which is 6ft (2m) longer and has almost twice the range. However, the tactical value of such a long-range missile is questionable, given the significant increase in targeting problems and the absence of any facility for mid-course guidance. The diameter of the pressure hull in the bow section is necessarily reduced because of the need to accommodate the missile tubes. Consequently the torpedo armament is relatively small by the standards of other modern Soviet attack submarines. There are six torpedo tubes as compared with eight in the Victor, and it is estimated that a maximum of 12 torpedoes could be carried. The Charlie II is almost certainly equipped to fire the SS-N-15 nuclear-tipped antisubmarine missile, and 26in (650mm) tubes may eventually be retro-fitted to enable these submarines to fire the SS-N-16 missile.

Electronics: The Charlie is credited with a low-frequency active/passive bow sonar, plus conformal passive flank arrays. Mast-mounted sensors conform to those of other Soviet submarines of the period: search and attack periscopes, a Snoop Tray surface surveillance radar, Park Lamp VLF/LF reception, Brick Pulp ESM, and HF and VHF communications. The Charlie II variant has twin hatches abaft the fin for a VLF communications buoy.

Construction: Twelve submarines of the Charlie I class were completed between 1968 and 1972 at the inland Gorky Shipyard. They were the first nuclear boats constructed at Gorky, which had previously built only diesel submarines. They were followed by six Charlie IIs, completed at the same yard between 1973 and 1982.

Below: The hatches covering the eight missile launch tubes are particularly prominent in this view of a Charlie I. Abaft the missile hatches can be seen a narrow, angled hatch which marks the location of the retractable forward hydroplanes. In the Charlie II the length of the bow section has been increased.

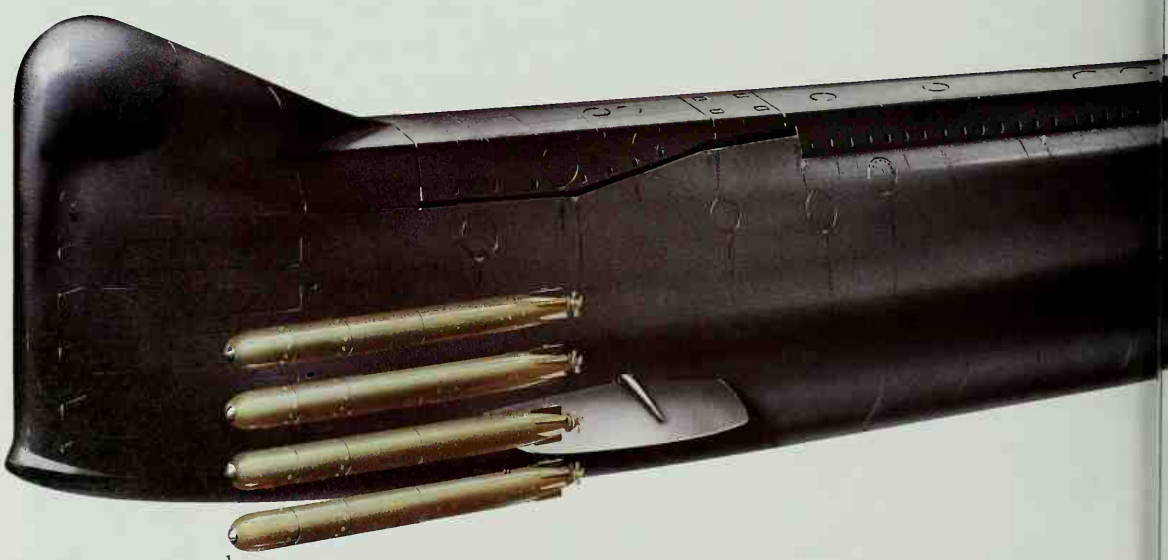


Daphné

Origin: France, first unit completed 1964
Type: Attack submarine, diesel-powered (SS)
Displacement: 870 tons surfaced; 1,045 tons submerged
Dimensions: Length 190ft (57.8m); beam 22ft (6.8m); draught 15ft (4.6m)
Propulsion: Diesel-electric drive on two shafts; two SEMT-Pielstick 12 PA 1/4 diesel generators, each 615bhp; two Jeumont Schneider electric motors, each 790hp; 1,230bhp for 13.5kt surfaced, 1,580hp for 16kt submerged
Complement: 45
Background: Prior to World War II the Marine Nationale had established a clear distinction between long-range ('1st Class') submarines of 1,500 tonnes, and medium-range ('2nd Class') submarines of about half that size. This policy was to continue in the postwar period. The Narval, which was closely modelled on the German Type XXI, became the standard 1st Class type, and in 1952 the General Staff requested that design work should begin on a 2nd Class counterpart, which was to become the Daphné. Staff requirements included low noise, good manoeuvrability, a small crew and ease of maintenance -- all features of the tiny Aréthuse design which preceded the Daphné. The last two requirements would be met by employing extensive automation, and by adopting unit replacement techniques to minimize onboard maintenance. In addition, maximum speeds of 13 knots dived, 6 knots creep speed, and 7 knots snorkeling were demanded. Diving depth was to be greater than in the preceding classes, and there were to be at least six internal torpedo tubes (of which two were to be stern tubes for antisubmarine torpedoes) with

Below: *Daphné*, the name-ship of the class. Although lacking in endurance, these submarines have proved handy in the relatively shallow waters of the Mediterranean and they carry a heavy armament of torpedoes.

***Daphné* (S 641)**



Above: The Daphné has an unusual arrangement of torpedo tubes reminiscent of French prewar practice. There are eight internal bow tubes, but the four stern tubes are external; two are directly above the stern, with the other pair angled out just forward of them. No reloads are carried. The torpedo tubes are of the traditional French 21.7in (550mm) calibre, and fire the older models of French torpedo. The E 14 and E 15 free-running anti-ship torpedoes (1) are complemented by the L 3 antisubmarine torpedo (2), which uses active acoustic homing. All three types are relatively slow by modern standards.

14 reloads and fire control on a par with the Narval class. These performance figures were generally exceeded in the final design, which incorporated no fewer than 12 torpedo tubes, of which eight were internal.

Design: The hull-form of the Daphné is conventional, with a prominent keel for improved stability during fast manoeuvres. The French continued to favour double-hull construction, with all fuel and ballast tanks outside the pressure hull. A maximum diving depth of 985ft (300m) is reported. Within the pressure hull there is a conventional single-deck layout. In keeping with French prewar practice all four stern tubes are external, the after pair being located directly above the stern with the other pair angled out just forward of them. Stern tubes were made possible by the adoption nf a two-shaft machinery installation allied to conventional control surfaces. The diesel-electric propulsion system introduced with great success in the Aréthuse class was retained, and the name-ship of the class achieved 16 knots on trials – an increase of three knots on the original specification. The machinery is mounted on two levels, with the auxiliary machinery above the propulsion machinery.

Armament: The Daphnés have eight internal bow tubes arranged as two vertical rows of four, plus the four external stern tubes already mentioned. However, as the design was very tight, reloads were dispensed with in order to economise on space. All 12 tubes are of the non-standard French prewar calibre of 21.7in (550mm); they are therefore limited to torpedoes of indigenous design and manufacture. French torpedoes of the period shared many common parts in order to facilitate production and maintenance. The E 14 anti-ship torpedo is 14ft (4.3m) long and has a passive acoustic homing head. It is relatively slow by modern standards, having a speed of only 25 knots and a maximum range of 8,300yds (7,500m). The E 15 is essentially an E 14 with an additional section which increases maximum range to 13,200yds (12,000m). The L 3, which is presumably fired from the stern tubes, is a free-running antisubmarine torpedo with active acoustic homing. Its length, speed and range are identical to the E 14's, but it can be fired down to a depth of 985ft (300m), twice the maximum firing depth of the anti-ship torpedoes.

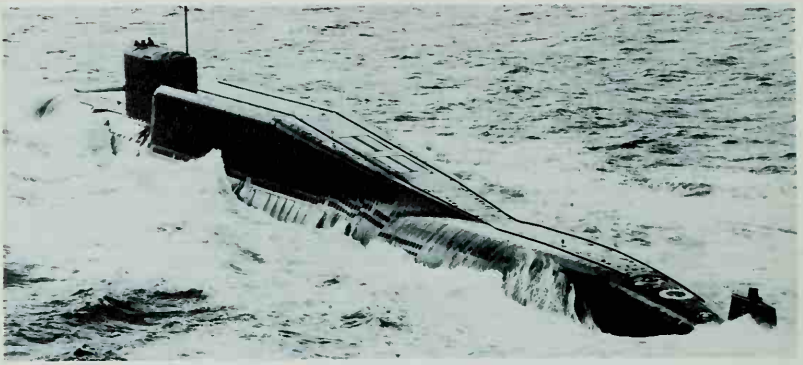
Electronics: As completed the Daphnés were fitted with a DUUA 1 active/passive scanning sonar, in a bulb above the stem; beneath the bow, in a larger dome, was a DSUV 2 circular passive array. The two primary sonars were complemented by a DUUX 2 passive ranging sonar for fire control, and an AUUD/DUUG 1 sonar intercept system to detect and analyse hostile sonar emissions. Torpedo fire control was provided by a DLT D-3 FC system. Search and attack periscopes were fitted, together with a Calypso surveillance radar and ESM intercept mast. Beginning in 1971 all except the name-ship, *Daphné*, underwent an extensive modernisation during which the submarines' electronics systems were substantially updated. The original DUUA 1 active/passive sonar was replaced by a DUUA 2 sonar housed in a prominent dome above the bow.

Construction: Eleven submarines of the Daphné class were completed for the French Marine Nationale between 1964 and 1970. Of these, *Minerve* was lost in 1968 and *Eurydice* in 1970. In addition, four were completed by French shipyards for Portugal between 1967 and 1969, three for Pakistan in 1970, and three for South Africa in 1970-71. One of the Portuguese boats was re-sold to Pakistan in 1975. Four further boats were built in Spain with French technical assistance and completed between 1973 and 1975.

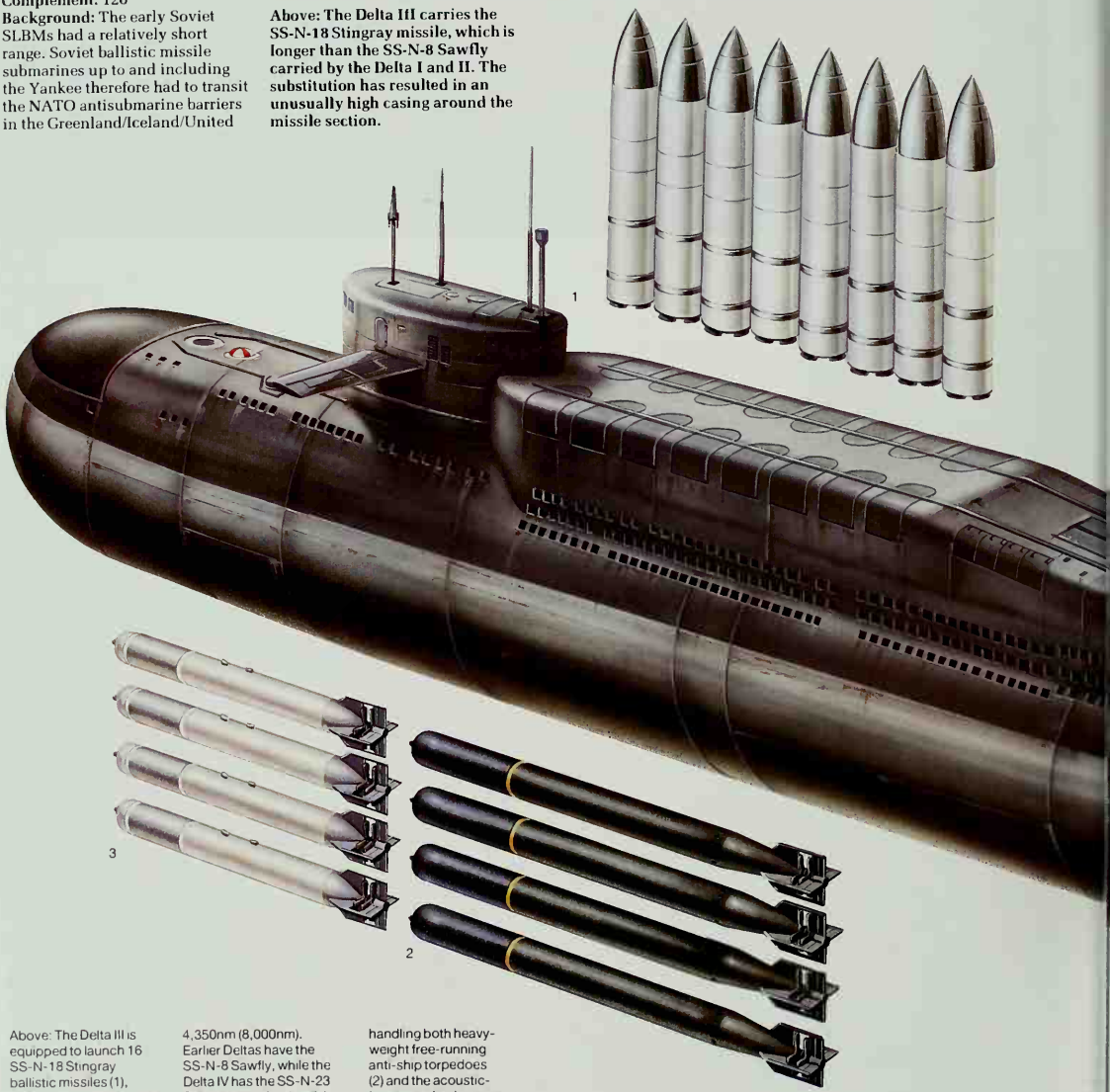
Below: The Daphné has proved to be an attractive export design. Besides the eleven boats completed for the Marine Nationale, ten have been built in French shipyards for other countries, and a further four have been built under licence.

Delta class

Origin: USSR, first unit completed 1972
Type: Ballistic missile submarine, nuclear-powered (SSBN)
Displacement: Delta I: 11,750 tons submerged
Delta II: 12,750 tons submerged
Delta III: 13,250 tons submerged
Delta IV: 13,550 tons submerged
Dimensions: Delta I: length 456ft (139m); beam 39ft (12m); draught 29ft (9m)
Delta II/III: length 508ft (155m); beam and draught as Delta I
Delta IV: length 538ft (164m); beam and draught as Delta I
Propulsion: Two pressurized water-cooled reactors driving geared steam turbines; 2 shafts; 35,000shp for 24-25kt max
Complement: 120
Background: The early Soviet SLBMs had a relatively short range. Soviet ballistic missile submarines up to and including the Yankee therefore had to transit the NATO antisubmarine barriers in the Greenland/Iceland/United



Above: The Delta III carries the SS-N-18 Stingray missile, which is longer than the SS-N-8 Sawfly carried by the Delta I and II. The substitution has resulted in an unusually high casing around the missile section.



Above: The Delta III is equipped to launch 16 SS-N-18 Stingray ballistic missiles (1), which carry between one and seven reentry vehicles to a range of 3,500nm (6,500nm) or 4,350nm (8,000nm). Earlier Deltas have the SS-N-8 Sawfly, while the Delta IV has the SS-N-23 Skiff (see text for details). The Deltas have six bow tubes of 21in (533mm) diameter capable of handling both heavy-weight free-running anti-ship torpedoes (2) and the acoustic-homing antisubmarine torpedoes (3) which are standard aboard Soviet submarines.

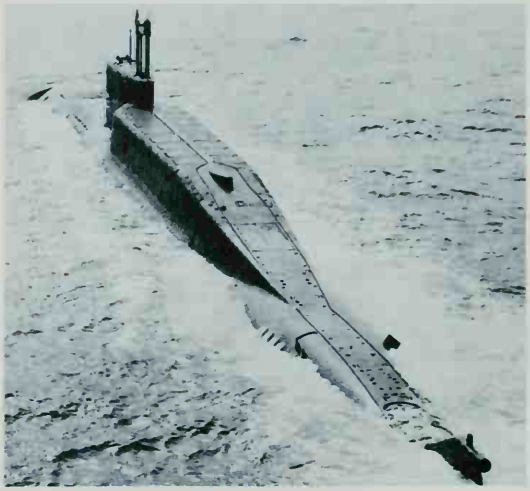
Kingdom (GIUK) Gap in order to target the United States. As Soviet missile technology progressed the possibility emerged of developing a missile with a range exceeding 4,000nm (7,500km), sufficient to target all major US cities from the relative security of Soviet-dominated waters in the Arctic and the Northwest Pacific. The SS-N-8, first installed in submarines of the Delta class, was to became the Soviet Navy's primary strategic missile, and spawned a number of later derivatives.

Design: The Delta is essentially a modified Yankee. The forward section, up to and including the fin, is identical to that of the earlier boat, as is the stern section. The major structural difference is the enlarged missile section amidships. The SS-N-8 is a much larger missile than the SS-N-6, so the compartment in which the missiles are housed is longer, broader and higher than that of the Yankee. In spite of a 30ft (9m) increase in length the Delta I could accommodate only 12 missiles as compared with 16 in the Yankee. Shortly after the appearance of the first Delta a new variant, the Delta II, entered service with the Northern Fleet. The missile section of the Delta II was the same height as that of the Delta I, but was 50ft (15m) longer, enabling four additional SS-N-8 missile tubes to be worked in. This gave the submarines an extraordinary length to beam ratio which was to be repeated in later Delta variants. The after end of the missile casing was not stepped, as in the Delta I, but was angled down to join the after section. The Delta III, which followed in 1978, was of identical length to the Delta II, but the missile casing was 8ft (2.5m) higher in order to accommodate a new MIRVed missile developed from the SS-N-8, the SS-N-18. The latest (and probably final) variant, the Delta IV, made its first public appearance in late 1985, again in the Northern Fleet area. It is in many respects identical to the Delta III. The new missile carried, the SS-NX-23, is similar in size to the SS-N-18, so the missile casing is largely unmodified. The major external differences are related to the stern, which has the same low, angular fin as the second and third boats of the Oscar class (qv). Fin stabilisers are fitted on either side of the hull casing aft, suggesting that the increased height of the missile section from the Delta III onwards may have resulted in stability problems.

Armament: The SS-N-8 carried by the Delta I and II is a large, liquid-fueled missile about 43ft (13m) long with a diameter of 6ft (1.8m). It is armed with a single large nuclear warhead of 800kT. The earliest variant of the missile had a maximum range of 4,250nm (7,800km), but the later Mod 2 variant has a range of 4,950nm (9,100km). The SS-N-18 missile carried by the Delta III entered service around 1978 and was the first Soviet SLBM to have multiple independent reentry vehicles. The Mod 1 variant of the missile carries three 200kT MIRVs to a maximum range of 3,500nm (6,500km); the Mod 2 is fitted with a single 450kT warhead and has a range of 4,350nm (8,000km); and the Mod 3 carries seven MIRVs and has a range similar to the Mod 1's. The SS-NX-23 missile which is due to enter service in 1985-86 in the Delta IV is an improved version of the SS-N-18, with greater throw weight and improved terminal accuracy. It will probably be retro-fitted in the Delta III, but cannot be carried by earlier boats without structural modifications. All variants of the Delta are fitted with six bow tubes for standard 21in (533mm) torpedoes. The Delta IV may also have the large-diameter 26in (650mm) tube.

Electronics: The Deltas appear to have the standard active/passive bow array first fitted in submarines of the Yankee generation. The outfit of sensor masts is also standard for submarines of their period, but with one important addition: the cone-shaped Pert Spring satellite communications antenna. As with the Yankee, a variant of the Cod Eye radio sextant is housed in the upper section of the fin.

Construction: Eighteen submarines of the Delta I class were completed between 1972 and 1977 at Severodvinsk in the Arctic and Komsomolsk in the Pacific. The four Delta II variants were completed at Severodvinsk in 1974-75, and the first of the Delta IIIs followed in 1975. Fourteen had been completed by 1985, the year in which the first of the Delta IVs appeared. Construction of the latter is continuing.



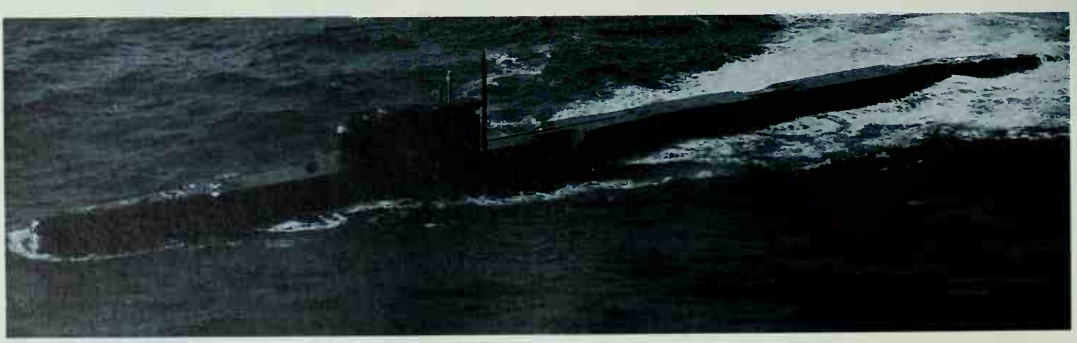
Above: The first of the new Delta IVs is seen here running on the surface. The Delta IV is similar in most respects to the Delta III, but carries the more advanced SS-N-23 missile. External differences include only a single pair of hatches for a VLF communications buoy on the angled section of casing, and a modified tail fin with a tubular dispenser for a towed array.

Left: The variant depicted here is the Delta III, which has a particularly prominent missile casing reaching almost to the top of the fin. The Delta I and II, which carry the shorter SS-N-8 missile, have a lower casing above the missile section. The Delta II, which carries 16 missiles, is of identical length to the Delta III, but the Delta I has only 12 missile launch tubes and is accordingly 56ft (18m) shorter.

Echo II class

Origin: USSR, first unit completed 1962
Type: Cruise missile submarine, nuclear-powered (SSGN)
Displacement: 5,200 tons surfaced; 6,200 tons submerged
Dimensions: Length 380ft (116m); beam 32ft (9.8m); draught 25ft (7.5m)
Propulsion: Two pressurized water-cooled reactors driving geared steam turbines; two shafts; 30,000shp for 23kt max
Complement: 100
Background: The Echo was the Soviet Navy's first purpose-built cruise missile submarine, earlier types being conversions of existing diesel boats. The first variant, the Echo I, was fitted with six paired launchers for SS-N-3C nuclear land attack missiles. However, a major policy change in 1959-60, which saw the creation of the Strategic Rocket Forces as an independent arm of the Soviet armed services and the institution of a large programme of land-based ICBMs, resulted in the premature termination of the Echo I programme after only five submarines had been laid down. The nuclear land attack mission was taken away from the Soviet Navy, which would henceforth concentrate on defending Soviet territory against attack from the sea. A modified version of the SS-N-3 Shaddock (NATO designation SS-N-3A) was developed for use against surface ships and installed in a new, enlarged Echo variant, the Echo II. A large radar antenna for mid-course tracking and guidance of the SS-N-3A missile was installed in a lengthened fin. Heavy reliance was placed on off-board sensors to provide initial detection and tracking of the target. In response to data provided by specially-equipped maritime reconnaissance aircraft such as the Tupolev Tu-95 Bear-D and communicated via a central command post ashore, the Echo would take up position on the bow quarter of a carrier task force and launch its missiles at maximum range.
Design: The Echo design, like that of the contemporary Hotel-class SSBN, was derived from the Soviet Navy's first SSN, the November. It has the same propulsion plant, comprising two reactors in series, each producing approximately 15,000shp. This has proved notoriously unreliable in service, and Echo-class boats have undergone frequent breakdowns while on patrol. The hull of the Echo II was lengthened by 20ft (6m) as compared with the Echo I in order to accommodate an additional pair of SS-N-3 launchers. The launch tubes are set flush with the upper corners of the hull casing, and elevate in pairs to an angle of about 15 degrees for firing. Prominent indentations in the hull casing abaft the launchers serve to deflect the blast of the missile exhaust upwards and outwards. These create considerable drag and noise when the submarine is running underwater, making the Echo relatively easy to detect using passive sonar techniques. The Front Door/Front Piece tracking/guidance radar is housed in the forward section of the fin, which rotates through 180 degrees when the antenna is deployed.
Armament: The eight SS-N-3A missiles originally fitted in all submarines of this class are now being replaced by the more recent SS-N-12 Sandbox, which first entered service aboard the antisubmarine carrier Kiev in 1975. The SS-N-3A has an estimated length of 33ft 6in (10.2m), while the SS-N-12, at 38ft (11.7m), is slightly longer. By 1984 10 boats were reported to have undergone conversion, and the programme appears to be continuing. A major drawback with both the SS-N-3 and SS-N-12 missiles is that they have to be launched from the surface, where the submarine would be vulnerable to early detection and preemptive strike. Preparation and

Below: The Echo was the first purpose-built Soviet SSGN. She has to remain on the surface during the lengthy launch preparations needed to enable her to fire her large SS-N-3 anti-ship missiles, but subsequent Soviet SSGN classes such as the Charlie and the Oscar can fire their missiles while submerged.



launch procedures take an estimated 25-30 minutes to perform, and the submarine has to remain on the surface to provide mid-course guidance. Six standard 21in (533mm) torpedo tubes in the bow can accommodate the standard anti-ship models, but in view of the age and primary mission of these submarines it is unlikely that they have received the fire control facilities necessary to accommodate more modern weapons. Four small stern tubes are fitted for 16in (400mm) antisubmarine torpedoes.

Electronics: As completed the Echo IIs were fitted with a passive Feniks bow array topped by a dome for the diminutive Hercules active sonar. The latter has been removed from all converted units of the class, and is also disappearing from unconverted boats. The sensor masts are fairly standard for Soviet submarines of the period: two periscopes, Stop Light ESM, Quad Loop DF, and HF and VHF communications aerials. However, in place of the customary surface surveillance radar the Echo IIs received a much larger air surveillance antenna, designated Snoop Slab. This was presumably necessary to provide warning of air attack while the submarine was surfaced and preparing to launch its missiles. It has been removed from converted units and replaced by the smaller Snoop Tray. Those boats fitted to fire the SS-N-12 missile have also received additional communications equipment, housed in bulged fairings on either side of the fin.

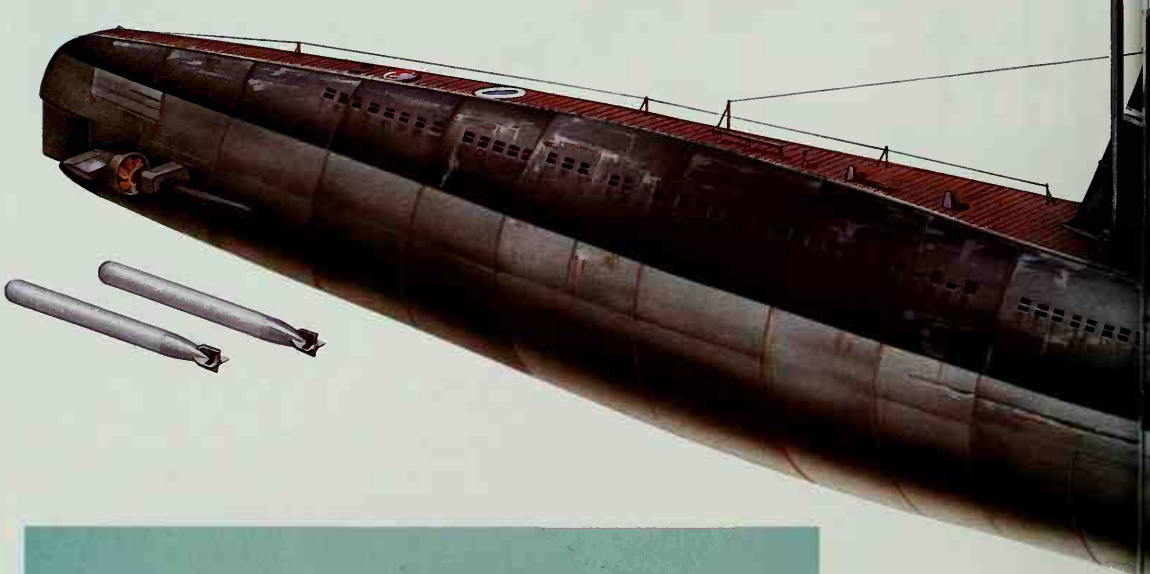
Construction: Twenty-nine Echo IIs were completed between 1962 and 1967; all but one remain in first-line service. Construction was shared evenly between Severodvinsk in the Arctic and Komsomolsk in the Pacific.

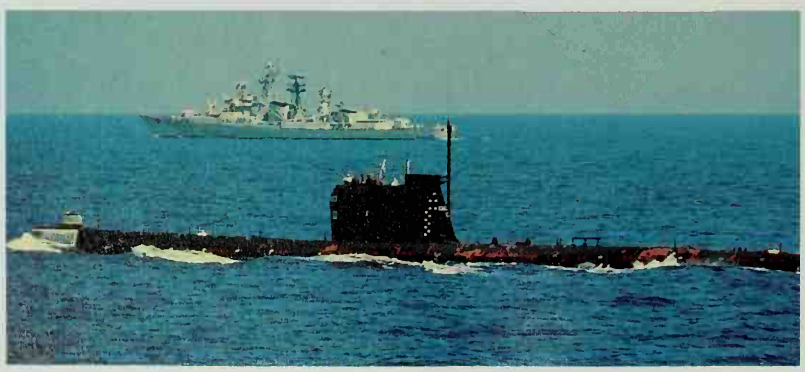
Above: The indentations in the outer hull casing are particularly prominent in this overhead view. They serve to deflect the missile exhaust, but cause considerable water turbulence around the hull. The missile launchers are paired, and are elevated for firing.

Left and below: The main armament of the Echo II comprises eight SS-N-3A Shaddock anti-ship cruise missiles (1) which are fired from elevating launchers stowed flush with the hull casing. Some units (variously reported as six or ten boats) have been modified to fire the SS-N-12 Sandbox missile, which is marginally longer and has a range of about 300nm (550km) as opposed to 250nm (460km) for the SS-N-3A Shaddock. Six bow torpedo tubes of 21in (533mm) diameter are fitted, and there are four smaller tubes of 16in (400mm) diameter in the stern. The bow tubes can handle standard free-running anti-ship torpedoes (2), which have either HE or nuclear warheads, while the stern tubes fire the short 400mm acoustic-homing torpedo (3), which would be used to defend the Echo against hostile submarines. Reloads are carried for both sets of tubes.

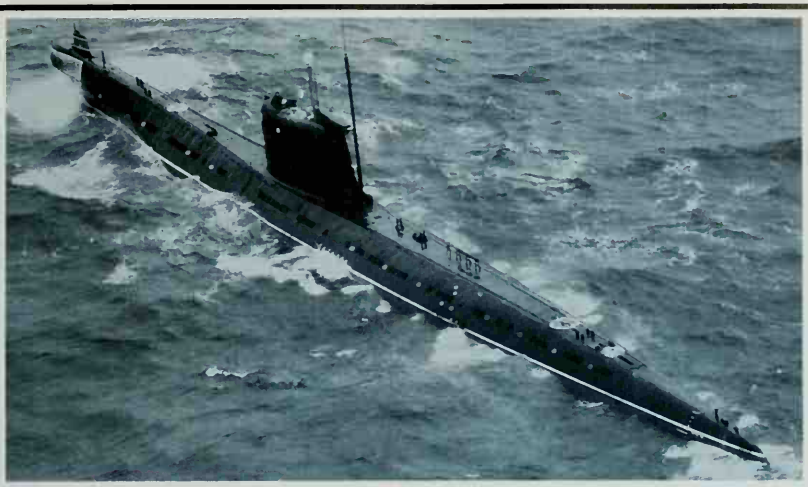
Foxtrot class

Origin: USSR, first unit completed 1958
Type: Attack submarine, diesel-powered (SS)
Displacement: 1,950 tons surfaced; 2,400 tons submerged
Dimensions: Length 300ft (91.5m); beam 25ft (7.5m); draught 20ft (6m)
Propulsion: Diesel/electric drive on three shafts; three diesels, three electric motors; 6,000bhp for 16kt surfaced, 5,300hp for 15.5kt submerged
Complement: 78
Background: The Soviet Navy had traditionally favoured a combination of large numbers of medium-range submarines for operations in Soviet coastal waters and a smaller number of long-range boats for scouting and reconnaissance. This policy found its classic expression in the Whiskey and Zulu classes of the 1950s, types which, in turn, found their natural successors in the Romeo and Foxtrot classes, the first units of which were completed in 1957-58. However, faced with a new threat from long-range carrier-based jet bombers capable of delivering a nuclear payload, the Soviet Navy was forced into premature termination of the medium-range Romeo in favour of larger submarines capable of intercepting hostile carrier task forces far from their bases. The Foxtrot and its nuclear-powered counterpart, the November, were ideal candidates to carry a newly developed torpedo with a nuclear warhead, designed for use against large formations of ships and port installations. In the event the November proved to be less than successful, and construction was shifted to the Echo-class SSGN (qv). The Foxtrot, on the other hand, proved to be a useful boat with a good general-purpose capability. It remained in production for the Soviet Navy until the late 1960s, and construction continued with a further 19 boats built for export to friendly countries during the 1970s and 1980s.
Design: In design terms the Foxtrot is essentially a refined Zulu. It retains the classic cigar shape of the German Type XXI, and the basic layout of machinery and torpedo tubes remains the same. However, whereas the Zulu was originally built with a stepped fin incorporating positions for small-calibre antiaircraft guns, the fin of the Foxtrot is altogether more streamlined. Moreover, the Zulu design made minimal allowances for the installation of modern sonar devices, whereas these are a major feature of the Foxtrot. Soviet reluctance to depart from the basic Zulu hull-form is, however, indicated by the installation arrangements for the passive sonar, which is incorporated into a specially-designed bulge above the traditional 'knife' bow. The retention of three shafts is also surprising, given that the centre shaft of the Zulu was thought to be associated with a closed-cycle propulsion system which was subsequently abandoned. Given a three-shaft arrangement and a slim, tapered stern it is difficult to see how the Soviet designers managed to accommodate the four standard stern tubes with which the Foxtrot is generally credited. Conventional after control surfaces are fitted, with a single large rudder incorporated in the stern, and the forward hydroplanes are fully retractable for surface operations in ice-bound waters.
Armament: The Foxtrot is reported to have a total of ten 21in (533mm) torpedo tubes, six of which are located in the bow and four in the stern. Anti-ship torpedoes with both conventional (HE) and nuclear warheads can be fired, and the Foxtrot can also presumably handle more recent antisubmarine models with acoustic homing. Stowage capacity is estimated at 22 torpedoes. These boats would be particularly useful for mining operations, for which each torpedo would be replaced by two mines. Some sources credit the Foxtrot with four small-diameter 16in (400mm) tubes for antisubmarine torpedoes in place of the 21in stern tubes, but it is not clear whether the smaller weapon was yet in service when the first Foxtrots were completed.
Electronics: The Foxtrot brought into service a new generation of Soviet sonar equipment. It has the classic combination of the passive Feniks array, housed in the bulged bow, and the active Herkules active attack sonar, topped by an underwater telephone in a small dome above it. There are also four fixed panels, each approximately 5ft (1.5m) square, disposed around the forward edge of the fin. These panels are also a feature of the contemporary November-class





Left: A Foxtrot operating with a missile destroyer of the Kashin class. The design has proved very successful, with more than 60 units completed for the Soviet Navy from 1958 to 1962 plus a further 19 units for export, but construction has now been terminated in favour of more modern types.

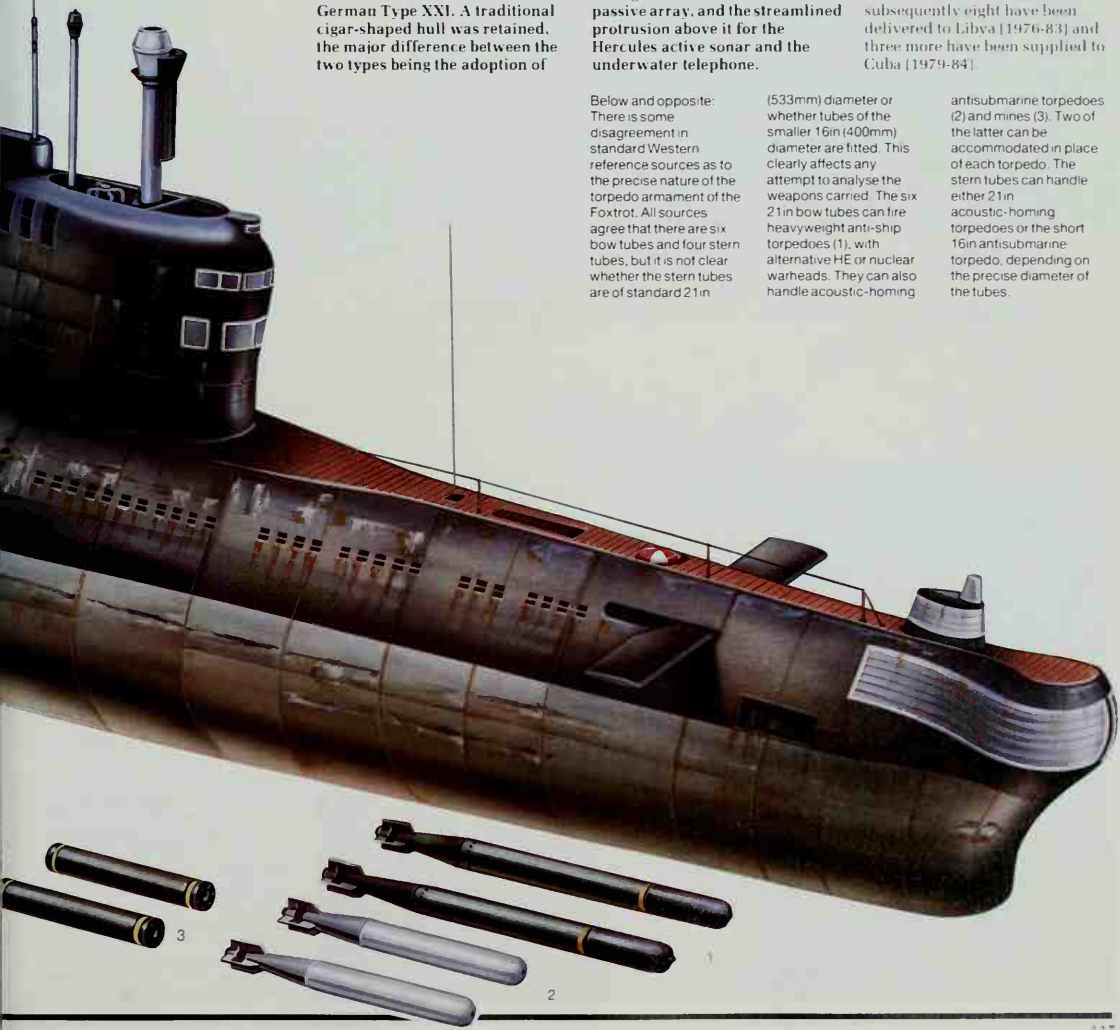


SSN and the Golf-class SSB, and are almost certainly components of a passive 'spot' hydrophone array, using the curve of the fin to obtain an accurate bearing on a contact. The sensor masts are standard for the period, search and attack periscopes, a Snoop Tray surface surveillance radar, Quad Loop direction-finding, Stop Light ESM, and aerials for VHF and HF communications. The latter is carried atop a hinged mast, as on the Echo and Golf classes, and folds back into a recess in the deck casing.

Construction: Sixty-two Foxtrots are estimated to have been built for the Soviet Navy, of which perhaps four have been lost. Construction has been exclusively at the Sudomekh Shipyard, Leningrad, which in the early 1970s merged with the Admiralty Shipyard to form the United Admiralty Shipyard. Soviet Navy construction probably ended in 1968. However, eight further boats of the class were completed for India between 1968 and 1974; subsequently eight have been delivered to Libya (1976-83) and three more have been supplied to Cuba (1979-84).

Above: The Foxtrot was the natural successor to the Zulu, which was in turn modeled on the German Type XXI. A traditional cigar-shaped hull was retained, the major difference between the two types being the adoption of more sophisticated sonar equipment. Note the rounded bow casing which houses the Feniks passive array, and the streamlined protrusion above it for the Hercules active sonar and the underwater telephone.

Below and opposite: There is some disagreement in standard Western reference sources as to the precise nature of the torpedo armament of the Foxtrot. All sources agree that there are six bow tubes and four stern tubes, but it is not clear whether the stern tubes are of standard 21in (533mm) diameter or whether tubes of the smaller 16in (400mm) diameter are fitted. This clearly affects any attempt to analyse the weapons carried. The six 21in bow tubes can fire heavyweight anti-ship torpedoes (1), with alternative HE or nuclear warheads. They can also handle acoustic-homing antisubmarine torpedoes (2) and mines (3). Two of the latter can be accommodated in place of each torpedo. The stern tubes can handle either 21in acoustic-homing torpedoes or the short 16in antisubmarine torpedo, depending on the precise diameter of the tubes.



Golf

Origin: USSR, first unit completed 1959
Type: Ballistic missile submarine, diesel-powered (SSB)
Displacement: 2,300 tons surfaced; 2,800 tons submerged
Dimensions: Length 321ft (98m); beam 28ft (8.5m); draught 21ft (6.5m)
Propulsion: Diesel-electric drive on three shafts; three diesels, each 2,000bhp; three electric motors, each 1,700hp; 6,000bhp for 17kt surfaced, 5,300hp for 12kt submerged
Background: Following World War II the Soviets acquired German rocket technology and developed missiles derived from the V-1 and V-2, and during the early 1950s experiments in towing a missile container behind a submarine – first undertaken by the Germans in 1944 – were revived; from these early experiments a new missile specifically designed for submarine launch was developed. The SS-N-4 Sark was a large three-stage liquid-fuelled rocket considerably larger than the early Polaris missiles of the US Navy and firing had to take place on the surface. The missile was fully 48ft (14.5m) long and was therefore too large to be accommodated in the submarine's hull. The solution adopted was to house the missile tubes in an elongated fin; this imposed serious constraints on the number of missiles which could be carried. The first Soviet ballistic missile submarines were converted boats of the Zulu class, the first of which entered service in 1958. The Zulu V, as it became known, had only two missile tubes, but it was followed by a purpose-built submarine, which became the Golf, with a larger fin housing three missile tubes. A nuclear-powered counterpart, the Hotel, was begun a year later, and parallel construction was established. However, the decision to establish the Strategic Rocket Forces resulted in early termination of the programme, and no more submarines of either type were laid down after 1960.
Design: The Golf is essentially a modified Foxtrot. The additional 25ft (8m) of length results from the need to accommodate three missile tubes in an elongated fin. Golf I-class boats modified for ballistic missile trials have been cut in half and have had an additional section inserted. The mast-mounted sensors are compressed into a relatively small space at the forward end of the fin, with the control/attack centre beneath. The diesel-electric propulsion system is identical to that of the Foxtrot, and the Golf has retained the Foxtrot torpedo tube arrangements.

1

2

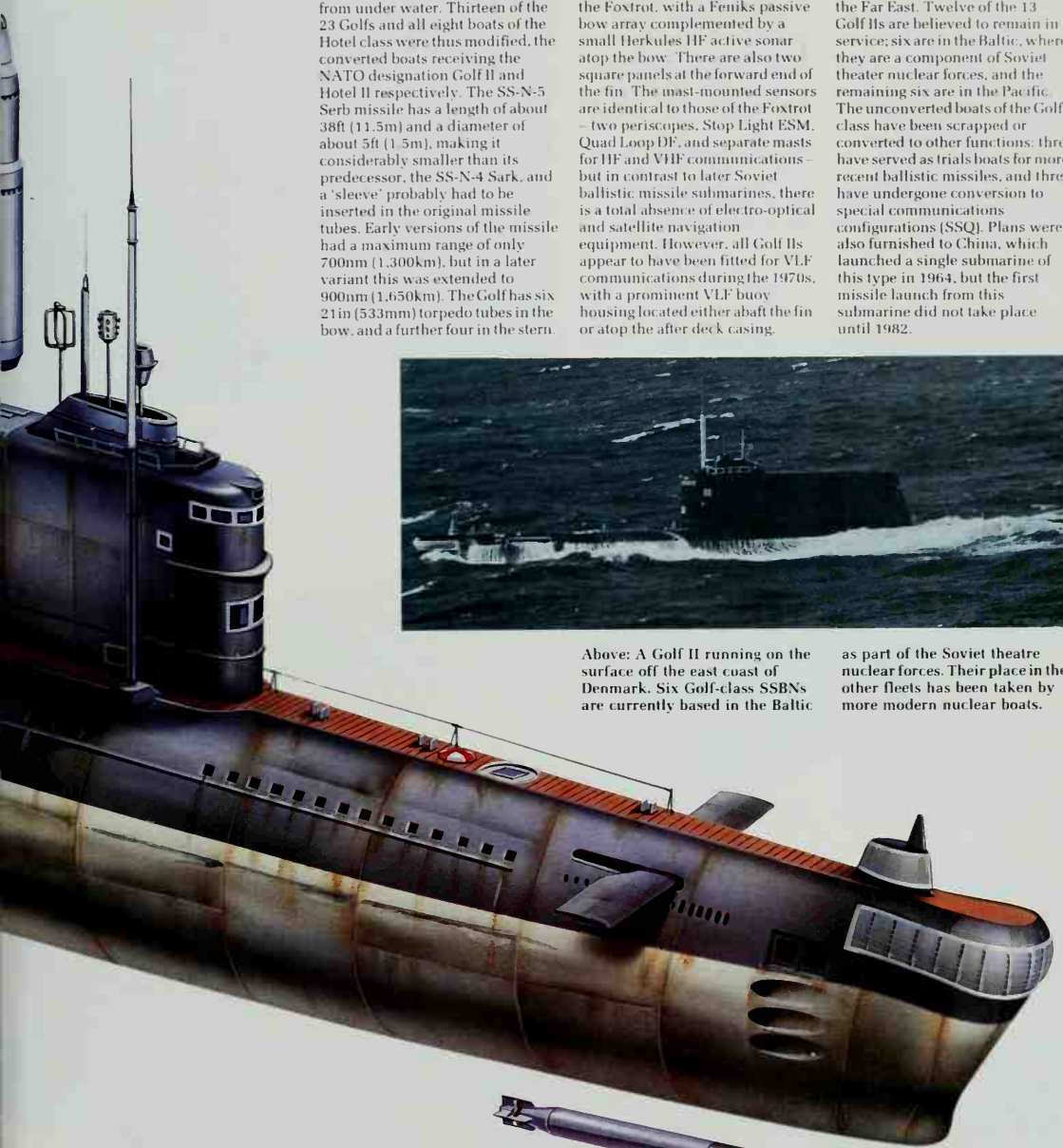
Left: A bow view of an SSBN of the Golf II class. Note the distinctive 'window' for the Feniks passive sonar wrapped around the bow, and the smaller sonar dome for the Herkules active attack sonar above it. The two square panels at the forward end of the fin, which are thought to be part of a passive ranging sonar, are particularly prominent in this view. Abaft the fin can be seen the housing for a VLF communications buoy which was added during the 1970s.

Armament: From 1963 onwards a limited modernisation programme was carried out which involved replacing the SS-N-4 Sark missile by the SS-N-5 Serb, which had twice the range and could be fired from under water. Thirteen of the 23 Golfs and all eight boats of the Hotel class were thus modified, the converted boats receiving the NATO designation Golf II and Hotel II respectively. The SS-N-5 Serb missile has a length of about 38ft (11.5m) and a diameter of about 5ft (1.5m), making it considerably smaller than its predecessor, the SS-N-4 Sark, and a 'sleeve' probably had to be inserted in the original missile tubes. Early versions of the missile had a maximum range of only 700nm (1,300km), but in a later variant this was extended to 900nm (1,650km). The Golf has six 21in (533mm) torpedo tubes in the bow, and a further four in the stern. Conventional anti-ship torpedoes can be fired, but it is unlikely that the submarines have been updated to handle more modern weapons.

Electronics: The Golf has a sonar outfit virtually identical to that of the Foxtrot, with a Feniks passive bow array complemented by a small Herkules HF active sonar atop the bow. There are also two square panels at the forward end of the fin. The mast-mounted sensors are identical to those of the Foxtrot – two periscopes, Stop Light ESM, Quad Loop DF, and separate masts for HF and VHF communications – but in contrast to later Soviet ballistic missile submarines, there is a total absence of electro-optical and satellite navigation equipment. However, all Golf IIs appear to have been fitted for VLF communications during the 1970s, with a prominent VLF buoy housing located either abaft the fin or atop the after deck casing.

Construction: Twenty-three submarines of the Golf class were completed between 1959 and 1962, 16 by the Severodvinsk shipyard in the Arctic, and the remaining seven at Komsomolsk in the Far East. Twelve of the 13 Golf IIs are believed to remain in service; six are in the Baltic, where they are a component of Soviet theater nuclear forces, and the remaining six are in the Pacific. The unconverted boats of the Golf I class have been scrapped or converted to other functions: three have served as trials boats for more recent ballistic missiles, and three have undergone conversion to special communications configurations (SSQ). Plans were also furnished to China, which launched a single submarine of this type in 1964, but the first missile launch from this submarine did not take place until 1982.

Above: A Golf II running on the surface off the east coast of Denmark. Six Golf-class SSBNs are currently based in the Baltic as part of the Soviet theatre nuclear forces. Their place in the other fleets has been taken by more modern nuclear boats.

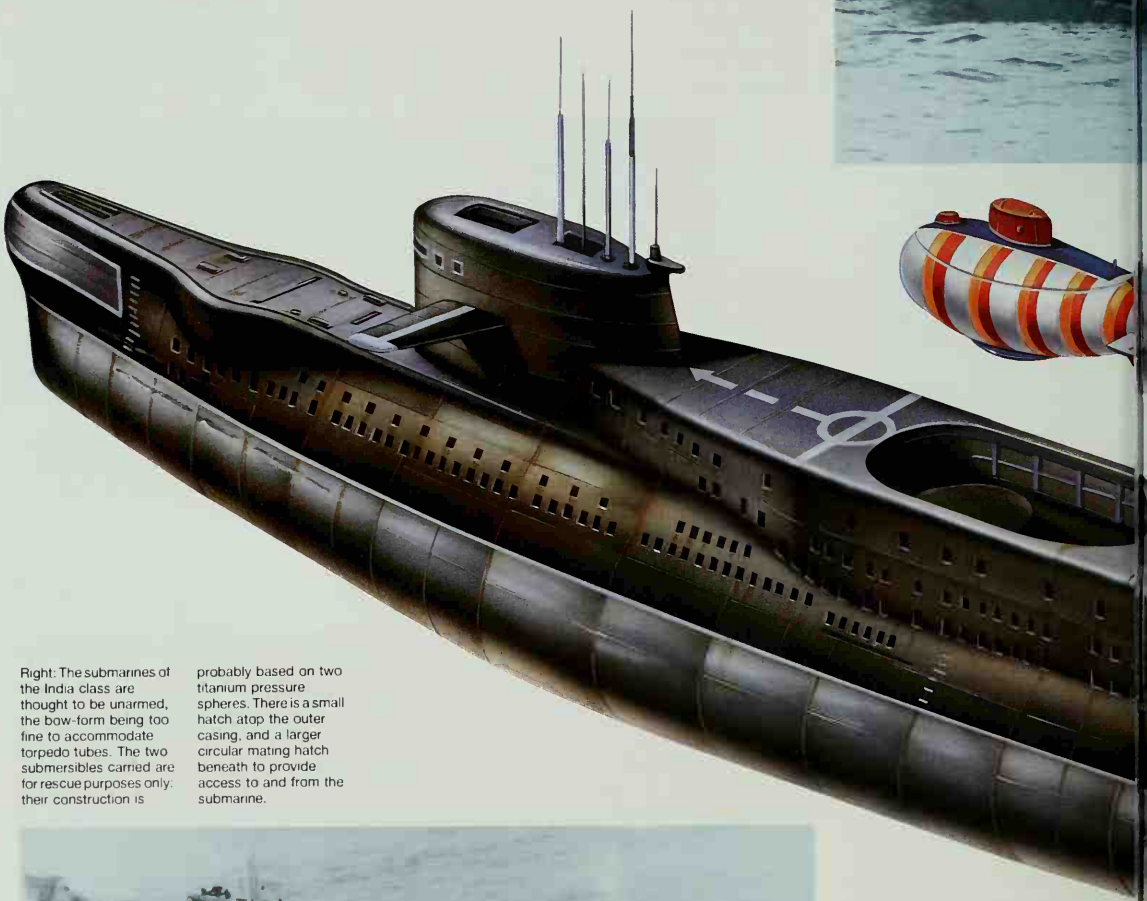


Above and right: The standard Golf II variant has three vertical launch tubes in the fin for SS-N-5 Serb missiles (1). These are now more than 20 years old, and even the later Mod. 2 variant has a range of only 900nm (1,650km). There are six bow torpedo tubes and four stern tubes, each of 21in (533mm) diameter.

The principal anti-ship weapon is probably the M-57 tree-running heavyweight torpedo (2) carried by contemporary diesel attack boats. The Golf IIs may also have been retro-fitted to fire the wire-guided antisubmarine torpedo (3) which is reported to have entered service with the Soviet Navy during the 1960s.

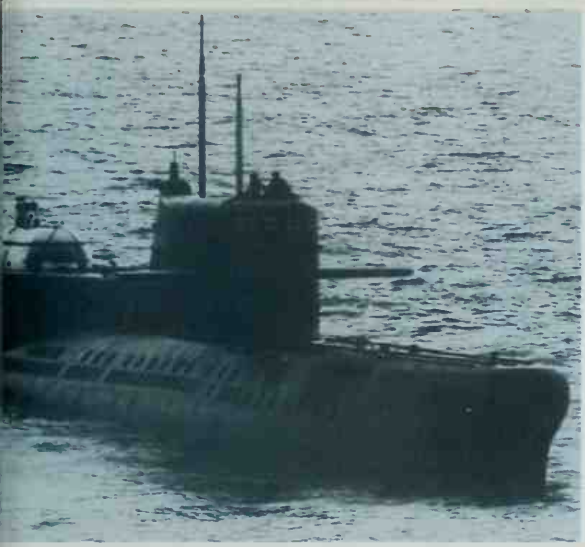
India

Origin: USSR, first unit completed 1979
Type: Auxiliary salvage and rescue submarine, diesel-powered (AGSS)
Displacement: 3,900 tons surfaced; 4,800 tons submerged
Dimensions: Length 348ft (106m); beam 33ft (10m); draught unknown
Propulsion: Diesel-electric drive on two shafts; two diesel generators, two electric motors; 4,000bhp for 15kt surfaced, 5,000hp for 15kt submerged
Complement: Unknown
Background: Interest in deep submergence rescue vehicles (DSRVs) began in the United States following the loss of the submarine *Thresher* (SSN-593) in 1963. Two specially-designed DSRVs, *Mystic* (DSRV-1) and *Avalon* (DSRV-2), were completed in 1971 and 1972 respectively to provide a capability for rescuing survivors from submarines disabled on the ocean floor above their hull-collapse depth. The US Navy DSRVs were designed for launch either from another submarine or from a submarine rescue ship of the Pidgeon (ASR-21) class, with an alternative long-distance rapid-deployment mode using a C-141 transport aircraft. The DSRV concept clearly influenced Soviet ideas, but when the Soviet Navy decided to embark on the construction of similar submersibles in the mid-1970s it opted for a completely different mode of deployment. The Soviet DSRVs would be carried by a mother submarine, rather in the manner of the Japanese Kaiten-carrying submarines of World War II. Such a submarine would also be well-suited to 'special' missions, for which it might embark divers or Spetsnaz commando units who would operate from small inflatables or from other types of small submersible. Two purpose-built submarines of the India class were subsequently completed, one of which is attached to each of the two Soviet fleets which operate nuclear-powered submarines, the



Right: The submarines of the India class are thought to be unarmed, the bow-form being too fine to accommodate torpedo tubes. The two submersibles carried are for rescue purposes only: their construction is probably based on two titanium pressure spheres. There is a small hatch atop the outer casing, and a larger circular mating hatch beneath to provide access to and from the submarine.

Left: One of the two auxiliary salvage and rescue submarines of the India class depicted during her transit from the Pacific to the Soviet Northern Fleet via the Arctic route; an ice guard is fitted over the bow to enable her to make the passage safely, and the two deck wells for submersibles set into the raised hull casing aft are covered by large steel plates. Note the bow-mounted diving planes.



Above: This view of the India shows the two rescue submersibles in place. They are semi-recessed in order to lower water resistance when the boat is running submerged. The outer hull casing of the India is lined with free-flood holes of a similar pattern to those of other conventional Soviet diesel boats such as the Foxtrot. A standard outfit of mast-mounted sensors is carried, including search and attack periscopes.

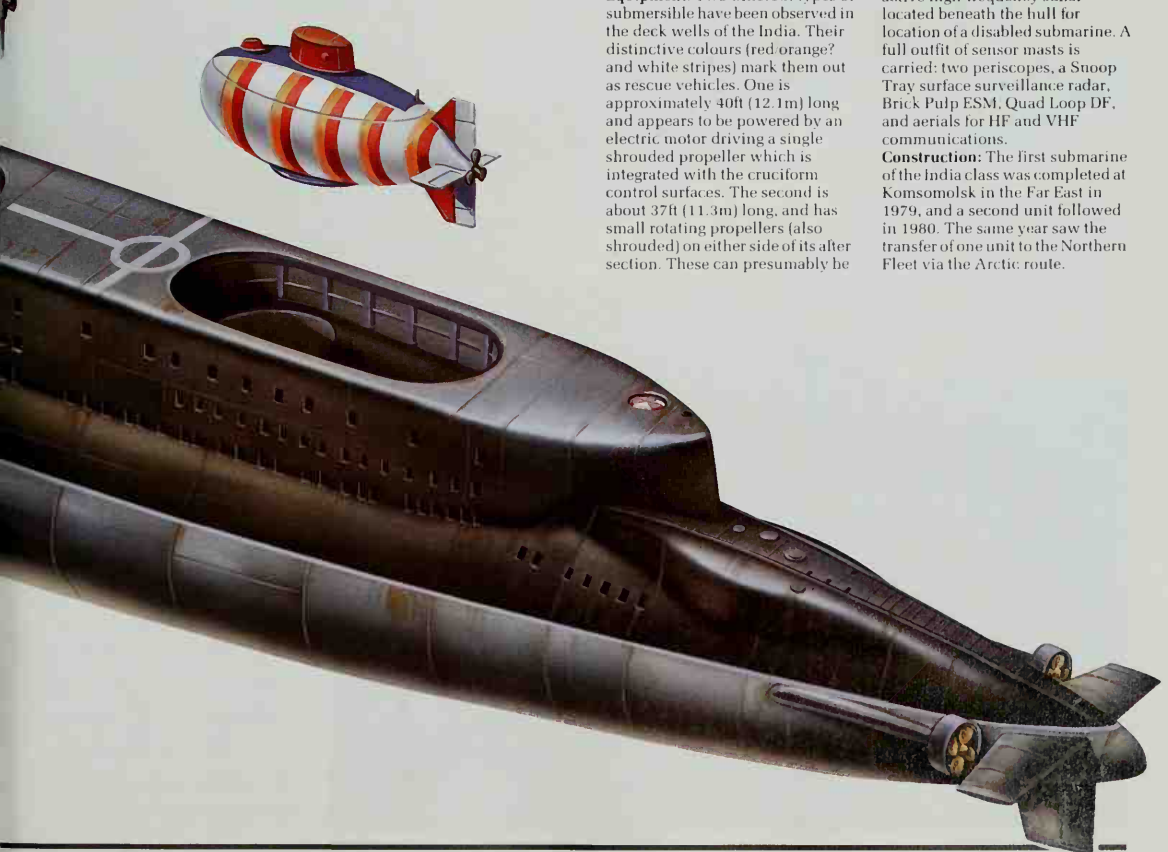
Northern Fleet and the Pacific Fleet.

Design: The India is a diesel-powered submarine of conventional double-hull construction. The basic configuration is reminiscent of the Foxtrot rather than the later Tango. The exceptionally fine bow, which is bulged above the water-line to accommodate a passive sonar, appears to have been adopted for high surface speed to enable the India to make a rapid transit to its operational area. It is probably too fine to accommodate torpedo tubes, so it seems likely that these submarines are completely unarmed. The long, relatively low fin is similar to that of the Yankee- and Delta-class SSBNs, and is located close to the bow. The India is the only type of Soviet submarine other than the Yankee and Delta to have its forward hydroplanes mounted on the fin. The after control surfaces are conventional, with a single vertical rudder beneath the stern. The two submersibles are carried semi-recessed in tandem deck wells abaft the fin. The deck wells are set into a prominent raised casing which extends almost to the stern. The submersibles mate with large circular hatches which give access to and from the submarine. When not in use the deck wells can be covered by large steel plates.

Equipment: Two different types of submersible have been observed in the deck wells of the India. Their distinctive colours (red/orange? and white stripes) mark them out as rescue vehicles. One is approximately 40ft (12.1m) long and appears to be powered by an electric motor driving a single shrouded propeller which is integrated with the cruciform control surfaces. The second is about 37ft (11.3m) long, and has small rotating propellers (also shrouded) on either side of its after section. These can presumably be angled in both the horizontal and vertical planes, and there are also cruciform tail surfaces. Both types have a large circular hatch beneath them to enable them to mate either with the mother submarine or with the submarine in distress. There is also a smaller hatch at the top of the submersible. Forward-looking optical viewing devices are fitted, and there are presumably also search and navigation sonars. The internal construction of the US Navy submersibles is based on three interconnected pressure-tight spheres made of HY-140 steel. The Soviet submersibles are somewhat shorter, and may therefore consist of two such spheres, probably of titanium. The forward sphere would house the controls and the two/three-man crew, while the after sphere would be able to accommodate 12-15 survivors. Other types of submersible may have been designed for clandestine operations, but none has yet been observed aboard the India. There has been some evidence of Soviet operations employing tracked submersibles in the coastal waters of Sweden, but neither of the two India-class submarines currently in service has deployed to the Baltic.

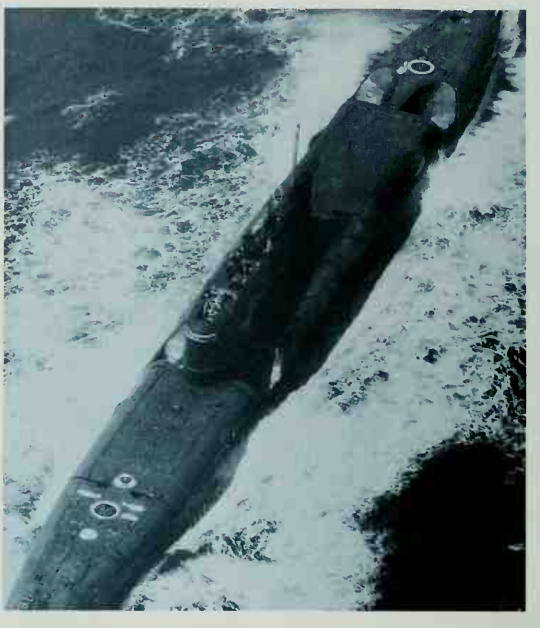
Electronics: The India has a medium-frequency passive array in the bow and presumably has an active high-frequency sonar located beneath the hull for location of a disabled submarine. A full outfit of sensor masts is carried: two periscopes, a Snoop Tray surface surveillance radar, Brick Pulp ESM, Quad Loop DF, and aerials for HF and VHF communications.

Construction: The first submarine of the India class was completed at Komsomolsk in the Far East in 1979, and a second unit followed in 1980. The same year saw the transfer of one unit to the Northern Fleet via the Arctic route.

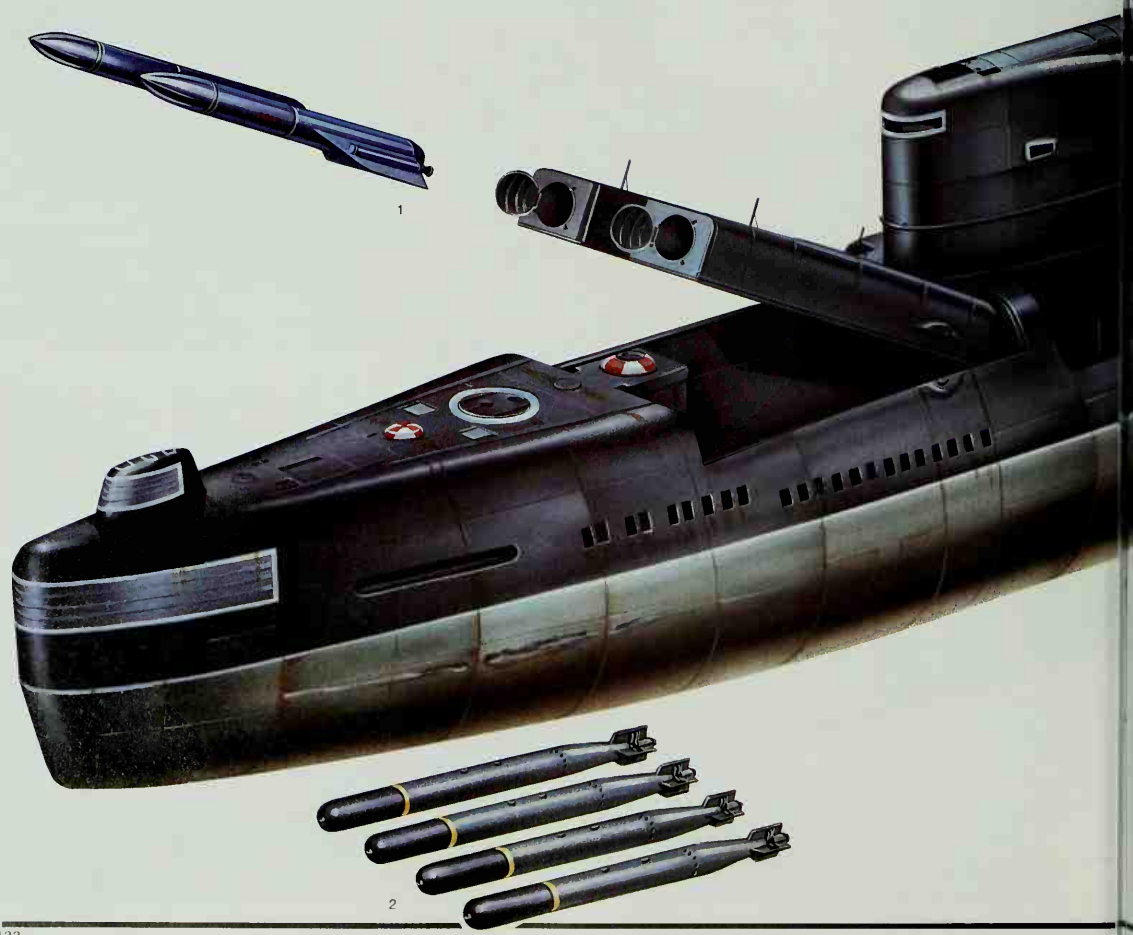


Juliett class

Origin: USSR, first unit completed 1962
Type: Cruise missile submarine, diesel-powered (SSG)
Displacement: 3,000 tons surfaced; 3,750 tons submerged
Dimensions: Length 285ft (87m); beam 33ft (10m); draught 23ft (7m)
Propulsion: Diesel/electric drive on two shafts; two diesels, two electric motors; 4,000bhp for 12kt surfaced, 3,400hp for 8kt submerged
Complement: 80
Background: The Juliett is the diesel-powered counterpart of the Echo (qv). In the early 1960s only two Soviet shipyards (Severodvinsk in the Arctic, and Komsomolsk in the Pacific) were capable of undertaking the construction of nuclear-powered submarines. The Soviets would therefore continue to rely heavily on other submarine building yards to make up the numbers with conventionally powered boats. Moreover, the Echo and the Juliett conform to the traditional Soviet pattern which combines large, complex '1st Rate' naval vessels and smaller, cheaper '2nd Rate' units which can be produced in greater numbers. It is reported that 72 Julietts were initially projected, but that in 1962 it was decided to restrict construction to only 16 units. Diesel propulsion makes the Juliett best suited to deployment close to Soviet territory in the anti-carrier role, and until the early 1980s all 16 boats of the class served with the Soviet Northern Fleet. However, the endurance of these submarines is such that they have seen frequent deployments to the Mediterranean, where they have often combined with other missile units to shadow the carriers of the US Sixth Fleet, and to the Indian Ocean.
Design: The Juliett design is derived from the Foxtrot. In spite of the obvious external differences resulting from the very different missions of the two submarines, they have a number of features in common. Length is virtually identical, and the submarines probably share a similar internal layout. However, the Juliett has a



Right: The Juliett is the diesel-powered counterpart of the Echo II. Four SS-N-3 missiles are carried in elevating launchers which are stowed flush with the broad upper casing.



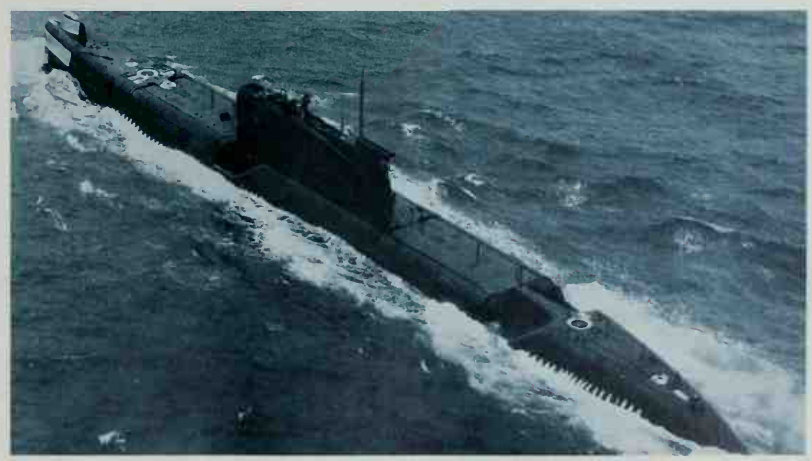
much broader outer casing in order to accommodate four launchers for SS-N-3A anti-ship missiles (half the number carried by the Echo II). The launchers are identical in configuration to those of the Echo, with the same prominent indentations in the hull casing behind them to deflect the blast of the missile exhaust. The fin is even longer than that of the Echo, as it has to accommodate a snorkel mast and diesel exhaust in addition to periscopes and the usual array of radar, ESM and communications antennae. It is, however, identical at its forward end, with a revolving section housing the Front Door Front Piece missile guidance radar. The propulsion machinery installation is a down-graded Foxtrot plant, with only two diesels and two shafts. This has resulted in a significant reduction in maximum underwater speed. The standard 21in (533mm) stern tubes of the Foxtrot have been replaced by four small-diameter tubes for antisubmarine torpedoes.

Armament: The SS-N-3A Shaddock anti-ship missile is about 33ft 6in long (10.2m) and weighs 12,000lb (5,400kg). It has a conventional aeroplane configuration, and is powered by a turbojet with two solid-fuel boosters slung beneath. It has a maximum range estimated at 250nm (450km), and employs active radar homing in the terminal phase. It requires mid-course guidance if it is to attain its maximum range. A specialised maritime reconnaissance bomber, the Bear-D, transmits its radar picture via a video data link to the launch submarine, and course corrections are then relayed to the missile in flight. The submarine has to remain on the surface during these operations. The SS-N-3A has alternative conventional or nuclear warheads, each weighing approximately 2,200lb (1,000kg). The torpedo tube arrangements are identical to those of the Echo, with six standard 21in (533mm) bow tubes for anti-ship torpedoes, and four 16in (400mm) stern tubes for antisubmarine torpedoes.

Electronics: The Juliett has the same Feniks passive bow array as the Echo, and early boats have the same diminutive active ranging sonar topped by an underwater telephone above the bow. Later boats have a larger active sonar with a 3ft (1m) wrap-around 'window'. The outfit of sensor masts is identical to that of the Echo, and includes the Snoop Slab air surveillance radar used to detect hostile aircraft while the submarine is conducting its lengthy preparations for missile launch. However, the HF communications mast is incorporated into the raised section of the fin which houses the diesel exhaust, whereas the Echo has its own HF aerial atop a prominent hinged mast which folds down into a recess in the deck casing. A few boats of the Juliett class have recently been fitted with bulged fairings on either side of the fin; these are identical to those fitted in Echo-class boats modified to fire the SS-N-12 missile, and are probably for communications equipment. However, there is as yet no indication that the SS-N-12 update programme is being extended to the Juliett.

Construction: Sixteen Julietts were completed between 1962 and 1969 at the inland Gorky Shipyard. This shipyard had previously been responsible for construction of the Soviet Romeos.

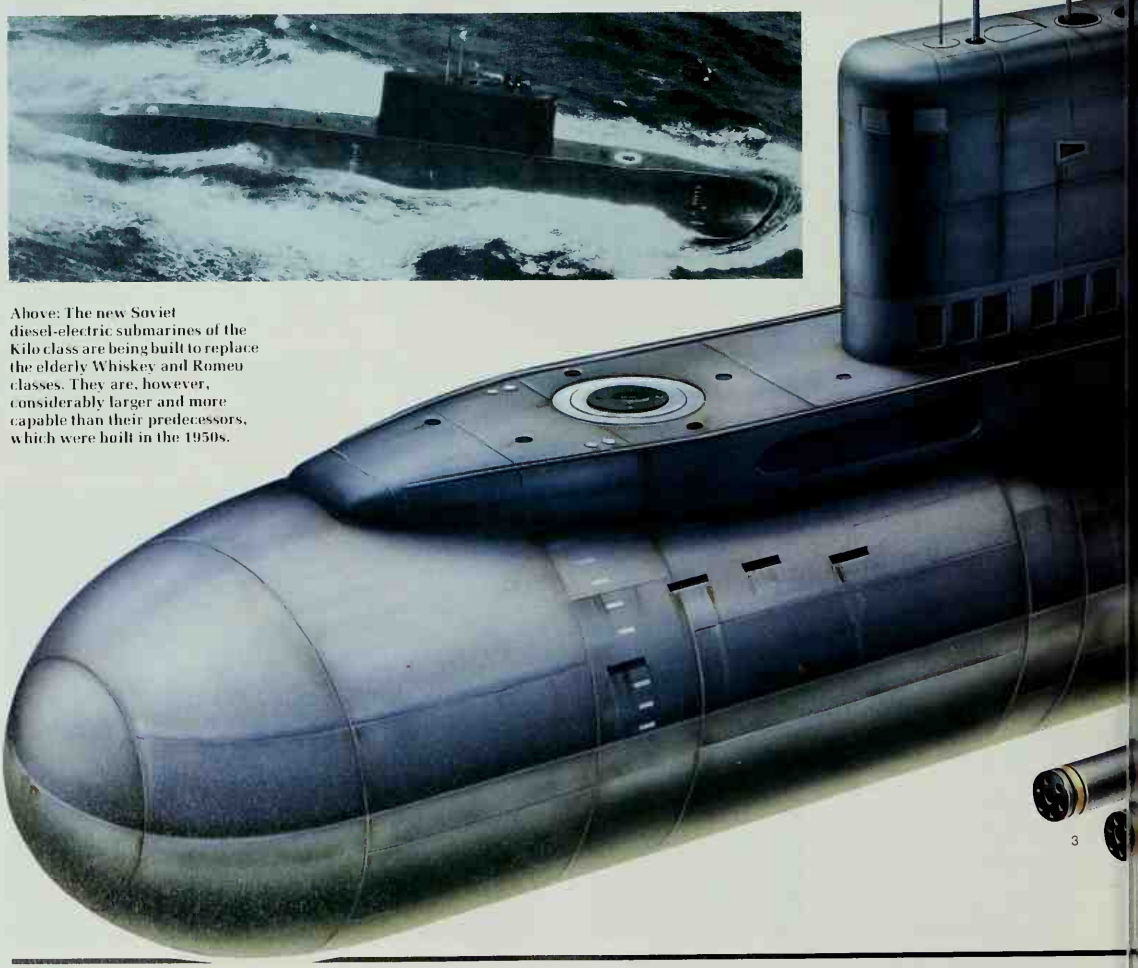
Opposite and above: The main armament of the Juliett comprises four SS-N-3A Shaddock anti-ship missiles (1), which are housed in elevating paired launchers stowed flush with the hull casing. There is as yet no evidence that Julietts are being retro-fitted to fire the SS-N-12. The Julietts have six 21in (533mm) bow tubes for long anti-ship torpedoes (2), and four 16in (400mm) stern tubes intended to launch short antisubmarine homing torpedoes (3).



Right: The prominent indentations in the upper hull casing are to deflect the missile exhaust. The Front Door Front Piece missile guidance radar is housed in the forward section of the fin, which rotates through 180 degrees when the radar is deployed. Preparations for missile launch have to be performed on the surface, thereby exposing the submarine to attack by aircraft.

Kilo class

Origin: USSR, first unit completed 1982
Type: Attack submarine, diesel-powered (SS)
Displacement: 2,500 tons surfaced, 3,000 tons submerged
Dimensions: Length 230ft (70m); beam 32ft (9.9m); draught 21ft (6.5m)
Propulsion: Diesel-electric drive on one shaft; two diesel generators, one electric motor; 4,000bhp for 12kt surfaced, 5,000hp for 16kt submerged
Complement: 60
Background: During the 1950s some 236 medium submarines of the Whiskey class were completed for the Soviet Navy. The Whiskey was followed by the improved Romeo design, but construction of this type was abandoned after only 20 had been laid down for the Soviet Navy. This appears to have been the result of a policy decision to terminate the construction of medium-range submarines in favour of the larger Foxtrot-class boat (q.v.), which was better suited to open-ocean operations. Nevertheless, the Whiskey was to remain the standard Soviet diesel boat throughout the 1960s, and was to prove its value in shallow-water operations in the Baltic and the Black Sea. Many were exported to friendly nations, including several of the countries belonging to the Warsaw Pact. However, by the mid-1970s most of the Whiskeys were more than 20 years old, and if their shallow-water mission was to be retained a replacement would have to be designed. This finally emerged as the Kilo, a comparatively large general-purpose submarine of conventional but modern design which would be built both for the Soviet Navy and for export.
Design: Externally the Kilo resembles modern Western diesel submarines much more closely than previous Soviet types. The hull is some 65ft (20m) shorter than that of the Tango, but beam has been increased by about 3ft (1m). The end result is a submarine remarkably similar in shape and size to the US Barbel and its Dutch derivatives of the Zwaardvis and Walrus classes, with an 'Alabacore' hull-form. There are, however, a number of subtle differences which mark out the Kilo as being of Soviet design and construction. The most important is the line of free-flood holes along the outer casing, which testifies to Soviet persistence with double-hull construction. The second difference is the longer fin, which is a feature of all Soviet submarines. A third difference is the position of the forward hydroplanes, which are located just beneath the deck casing immediately forward of the fin, not on the fin as in their US Navy and Dutch counterparts. The hydroplanes are fully retractable as on other Soviet boats to prevent ice damage during surface operations in northern waters. A rather more surprising feature of the Kilo is Soviet persistence with the after control surfaces employed in earlier diesel submarines such as the Foxtrot and Tango in preference to the cruciform tail surfaces now standard on their nuclear boats. The main rudder is beneath the stern, although there is a small 'tab' visible above the water. The function of the latter is not clear, although it may be a component of a hull-mounted passive array. In spite of the unusual rudder arrangement there is only a single shaft with a six-bladed propeller; all earlier Soviet diesel boats had a multi-shaft arrangement with the control surfaces abaft the propellers.
Armament: The Kilo has six bow tubes of 21in (533mm) diameter. These can fire the standard Soviet anti-ship and antisubmarine torpedoes. As an alternative payload, each torpedo can be replaced by two mines. It is not



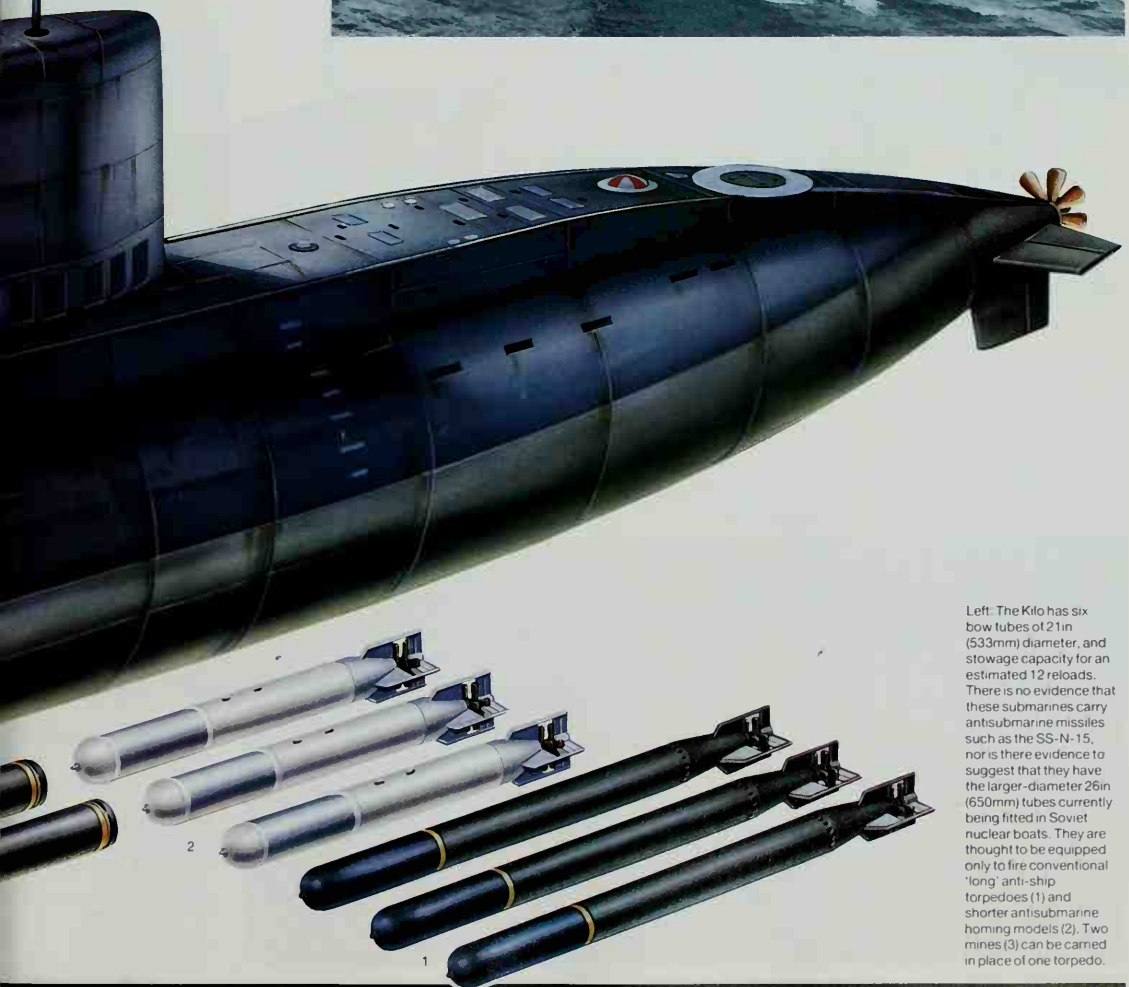
Above: The new Soviet diesel-electric submarines of the Kilo class are being built to replace the elderly Whiskey and Romeo classes. They are, however, considerably larger and more capable than their predecessors, which were built in the 1950s.

clear whether the Kilo is fitted to fire the SS-N-15 antisubmarine missile. The latter can be fired from a standard torpedo tube, but the Kilo has a relatively limited weapons stowage capacity estimated at only 12 torpedoes, and it is in any case questionable whether the submarine's designed mission includes the engagement of hostile submarines with nuclear weapons. Nor is there any evidence that the Kilo is fitted with large-diameter 26in (650mm) tubes capable of firing the SS-N-16 antisubmarine missile or the Type 65 wake-homing torpedo.

Electronics: The Kilo is equipped with a low-frequency active/passive bow sonar, and is presumably also fitted with hull-mounted passive hydrophone arrays. However, there is no indication that a towed hydrophone array comparable to those of the more recent Soviet nuclear-powered attack boats is fitted. The mast-mounted sensors belong to an earlier generation of submarines. The elderly Stop Light ESM antenna is fitted in place of the more recent Brick Pulp, and Quad Loop DF in place of Park Lamp. In addition the Kilo is equipped with search and attack periscopes, a Snoop Tray surveillance radar, and HF and VHF communications aerials.

Construction: The first Kilo was completed by the Komsomolsk Shipyard in the Far East in 1982, and the class has since entered series production. Ten units have so far been completed for the Soviet Navy, and a further three are under construction. Production has now been extended to shipyards in the western USSR at Gorky and Leningrad (the United Admiralty Shipyard, formerly Sudomekh), and it is thought that the latter two yards will build the submarine for export customers such as India, reported to have placed orders for three boats in April 1984.

Right: In spite of her double-hull construction, the Kilo bears a striking similarity to contemporary Western diesel-electric submarines derived from the US Barbel class, being both shorter and beamier than earlier Soviet diesel boats. The class has now entered series production for the Soviet Navy, and is also being offered to friendly Third World countries.



Left: The Kilo has six bow tubes of 21in (533mm) diameter, and stowage capacity for an estimated 12 reloads. There is no evidence that these submarines carry antisubmarine missiles such as the SS-N-15, nor is there evidence to suggest that they have the larger-diameter 26in (650mm) tubes currently being fitted in Soviet nuclear boats. They are thought to be equipped only to fire conventional 'long' anti-ship torpedoes (1) and shorter antisubmarine homing models (2). Two mines (3) can be carried in place of one torpedo.

Lafayette class

Origin: USA, first unit completed 1963
Type: Ballistic missile submarine, nuclear-powered (SSBN)
Displacement: 7,350 tons surfaced; 8,250 tons submerged
Dimensions: Length 425ft (129.5m); beam 33ft (10.1m); draught 29ft (8.8m)
Propulsion: One S5W pressurized water-cooled reactor driving geared steam turbines; one shaft: 15,000shp for 20+kt
Complement: 140
Background: The first ballistic missile submarines built for the US Navy, the five SSBNs of the George Washington class, were converted Skipjacks with an additional 130ft (40m) missile section inserted abaft the fin. They were followed by five boats of the Ethan Allen class which, although generally similar in layout to their predecessors, were designed as SSBNs from the outset. They were also longer and had a number of features in common with the Thresher class SSNs, including superior silencing and a hull constructed of HY80 steel. The Ethan Allen was to form the basis of an improved design which became the Lafayette class. The Lafayette was the standard US Navy SSBN throughout the 1960s and 1970s, and had a major influence on the design of other Western SSBNs, notably those of the British Resolution and French Le Redoutable classes (qv).
Design: The early boats of the Lafayette class differed little from the Ethan Allen class in terms of their general layout and weapon/sensor technology. The major difference was in the missile tubes themselves, which were enlarged to accommodate future ballistic missiles of greater diameter than Polaris. This increased overall length by 15ft (4.5m), while the submarine's other dimensions remained unchanged. An essential part of the deterrence mission of the Lafayettes was the avoidance of hostile submarines. The sonar outfit was therefore biased towards detection rather than long-range fire control. The spherical bow sonar which was a feature of the Thresher design was not installed in US Navy SSBNs, which could therefore accommodate their torpedo tubes in the bow in the conventional manner. The S5W reactor is the same model as that installed in the SSNs, and the large size of the Lafayettes means that they are relatively slow. Quietness, however, has always been accorded much greater priority than high performance in US SSBN designs, and the last 12 units of the class (officially known as the Benjamin Franklin class), incorporated further improvements in machinery noise insulation. The large fin is based on that of the Skipjack, and carries the forward hydroplanes. One unit, the *Daniel Webster* (SSBN 626) was fitted with bow planes for evaluation.
Armament: The first eight units of the class entered service with the Polaris A-2 missile, which had a single nuclear warhead and a range of 1,500nm (2,800km). The remaining 23 boats received the A-3 variant, which had three MRVs

Below: The Lafayette class set the standard for Western ballistic missile submarines, both the British Resolution and the French Le Redoutable classes being based on these US Navy boats. The 16 launch tubes for the C-3 Poseidon missiles are located immediately abaft the fin. The unit depicted here, the *Nathaniel Greene* (SSBN 636), belongs to the earlier sub-group of the class: later units have been retro-fitted with the Trident missile.

Above and right: Earlier units of the Lafayette class retain the Poseidon C-3 SLBM, but the last 12 boats have been retro-fitted with the Trident-I C-4 missile (1). Sixteen missiles are carried in two rows each of eight launch tubes. All earlier models of torpedo have now been superseded by the high-performance Mk 48 (2), which can be used against surface ships or submarines. There are four bow tubes.

Above: The *Sam Rayburn* (SSBN 635), was the first submarine of the Lafayette class to be deactivated. This step was necessary in order to conform with the ceiling imposed on US SLBMs by the SALT II Treaty.

and a range of 2,500nm (4,600km). The A-3 missile was subsequently retro-fitted in the early boats. In 1970 the C-3 Poseidon missile entered service, and was to replace the A-3 in all submarines of the Lafayette class. Poseidon, a fatter missile than Polaris, with a length of 34ft (10.4m) and a diameter of 6ft 2in (1.9m), had a similar range to the Polaris A-3, but could carry ten 50kT MIRVed warheads. It remains in service aboard the surviving early units of the class, but since 1979 the 12 SSBNs of the Benjamin Franklin sub-group have been progressively converted to fire the Trident C-4 missile. The latter was designed to be compatible with the launch tubes of the Lafayette class, and has overall dimensions identical to Poseidon. It carries eight 100kT MIRVed warheads to a range of 4,000nm (7,400km). The increase in range has enabled submarines equipped with Trident to be withdrawn from forward-basing in Europe. The four bow torpedo tubes initially handled the same weapon mix as US Navy SSNs of the period (see Permit), although the Lafayettes were apparently not fitted to fire SUBROC. The early models of torpedo have now been superseded by the Mk 48.

Electronics: The sonar outfit installed at completion was essentially that of the Skipjacks: a BQS-4 active/passive sonar inside a circular BRQ-2C passive array in the bow, plus a conformal BQR-7 hydrophone array along the hull. The Lafayettes were fitted with Mk 88 missile fire control, and the standard Mk 113 torpedo fire control system. From 1974 onwards all submarines of the class underwent a sonar update programme. The BQR-2C passive array was replaced by the BQR-21 model, which has Digital Multi-Beam Steering (DIMUS), enabling five targets to be tracked simultaneously. A mast-mounted BQR-19 sonar was also fitted, to enable the submarines to avoid surface ships. The third element in the update programme was the BQR-15 towed array, which was installed for more effective detection of hostile hunter-killer submarines. Trident conversions have also received three Mk 2 SINS for more accurate navigation.

Construction: Thirty-one submarines of the Lafayette and Benjamin Franklin classes were completed between 1963 and 1967 at four different shipyards. Of these, three have now decommissioned to enable the United States to remain within SALT II Treaty limits.

Lafayette class *Daniel Boone* (SSBN 629)

Le Redoutable class

Origin: France, first unit completed 1971
Type: Ballistic missile submarine, nuclear-powered (SSBN)
Displacement: 8,000 tons surfaced; 9,000 tons submerged
Dimensions: Length 420ft (128m); beam 35ft (10.6m); draught 33ft (10m)
Propulsion: One pressurized water-cooled reactor with turbo-electric drive; two turbo-alternators driving one main electric motor; one shaft; 16,000hp for 20kt
Complement: 135
Background: In the early 1960s France embarked on the development of a Force de Dissuasion which was initially to be based on a force of five SSBNs. The programme not only served to reinforce the incipient political separation between France and the United States, but also marked the birth of an independent technology which would see the development of both nuclear reactors and ballistic missiles of French design and manufacture. The first reactor, the PAT 1, was produced in collaboration with the CEA (the French Atomic Energy Authority) and tested extensively ashore at Cadarache. Development of the missile took place simultaneously, the first French SLBM being launched from the experimental submarine *Gymnote* in 1968. Construction of the SSBNs posed a number of technical problems, including the development of high-tensile steel to cope with a required diving depth of 300m.
Design: The overall design was closely based on that of the US Navy's Lafayette class (q.v.), and these boats were the first French postwar submarines to have a single hull. They also have the fin-mounted forward hydroplanes and the cruciform after control surfaces of their US counterparts, the 16-missile SLBM compartment is located directly abaft the fin, with a three-deck accommodation layout forward and the machinery spaces aft; the torpedo handling room is in a smaller cone directly behind the four bow tubes. The propulsion system is unusual in that the single PWR reactor does not drive geared steam turbines, as in other Western SSBNs of the period, but drives two turbo-alternators, which in turn provide the power for a single large electric motor. An auxiliary SEMT-Pielstick 16 PA 4 850kW diesel generator provides sufficient power in an emergency to get the submarine back to its

Above: *Le Redoutable* was the first of five SSBNs completed for the Marine Nationale during the 1970s. The nuclear reactors and the missiles were developed without US assistance.

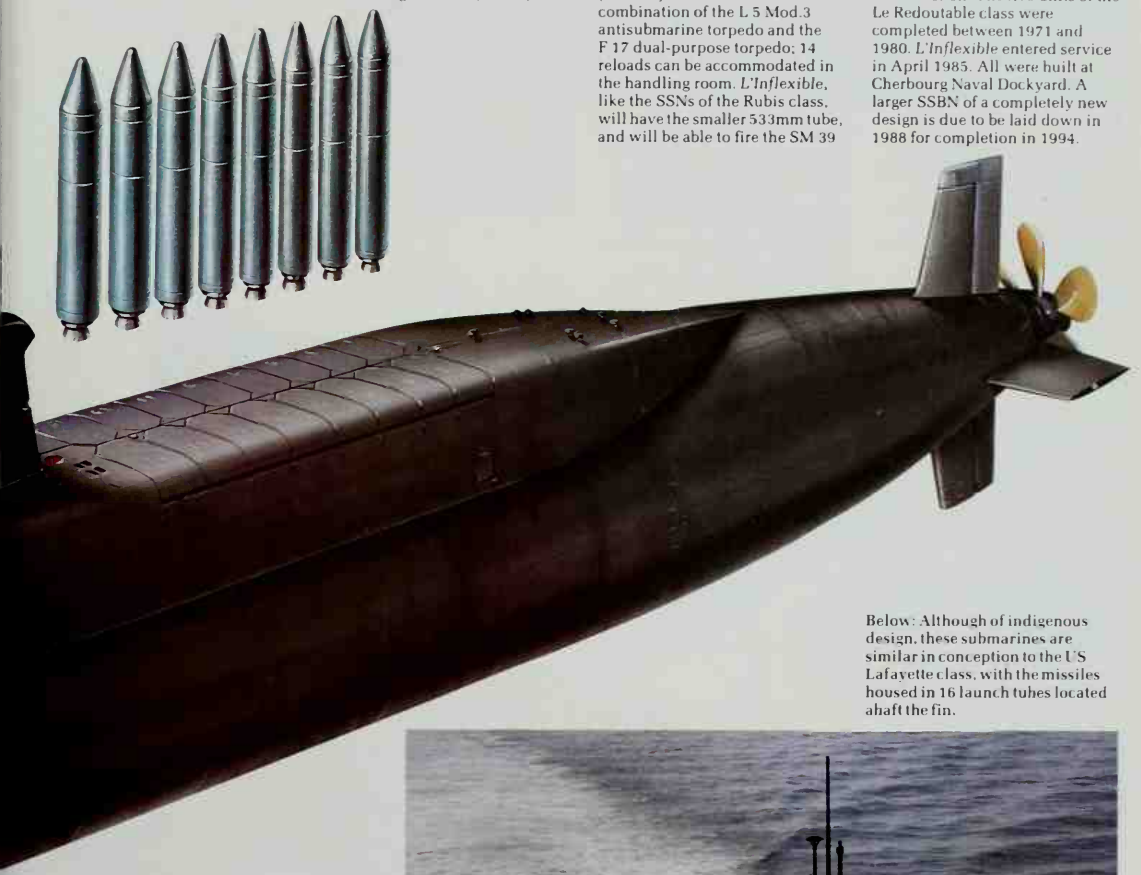
Le Redoutable class *Le Tonnant* (S 614)

home base. The fourth and fifth boats, *L'Indomptable* and *Le Tonnant*, have a metallic reactor core in place of the oxide cores of the earlier boats. The sixth boat, *L'Inflexible*, is of an improved type and is officially regarded as a separate class. Her missile compartment has been modified to accommodate the M 4 SLBM from the outset, and she has quieter machinery and more advanced electronics. *L'Inflexible* can be distinguished externally from her sisters by her re-shaped fin, with the hydroplanes mounted high on the forward edge.

Armament: The first two units of the class, *Le Redoutable* and *Le Terrible*, initially carried the M 1 missile, which comprised a two-stage rocket with a single 500kT nuclear warhead and a range of 1,350nm (2,500km). The M 1 was superseded in the third unit, *Le Foudroyant*, by the M 2, with a more powerful second stage which increased range to 1,600nm (3000km). The next two units, *L'Indomptable* and Le Tonnant, entered service with a mix of M 2 and M 20 missiles, the latter being identical in performance to the M 2 but carrying a thermo-nuclear warhead of 1MT. Since 1977 the earlier units have carried the same mix. Both the M 2 and the M 20 have a length of 34ft (10.4m) and a diameter of 5ft (1.5m). The M 4, which is about to enter service on the sixth boat, *L'Inflexible*, is a completely new missile employing more advanced propulsion and warhead technology; it has a length of 36ft (11.05m) and a diameter of 6ft 4in (1.93m). Range is 2,150nm (4,000km) in the current version, and this will be increased to 2,700nm (5,000km) in the M 4B. The multiple warhead comprises six TN-70 MIRVs, each of about 150kT. With the exception of *Le Terrible*, all the early boats of the class will be retro-fitted with the M 4 missile, beginning in 1985 with *Le Tonnant*. The four 21.7in (550mm) bow tubes can fire a combination of the L 5 Mod.3 antisubmarine torpedo and the F 17 dual-purpose torpedo; 14 reloads can be accommodated in the handling room. *L'Inflexible*, like the SSNs of the Rubis class, will have the smaller 533mm tube, and will be able to fire the SM 39 Exocet missile in addition to torpedoes.

Electronics: The first five units are fitted with the DUUV 23 panoramic passive array and the DUUX 2 ranging sonar, but *L'Inflexible* has the new DSUX 21 multi-function sonar in place of the DUUV 23, plus the DUUX 5 digital ranging sonar. It is envisaged that the DSUX 21 will be retro-fitted to the other boats during their M 4 refits. The submarines' position can be accurately determined by reference to three inertial navigation centres (CIN) ashore, and there is a periscope for terrestrial navigation.

Construction: The five units of the Le Redoutable class were completed between 1971 and 1980. *L'Inflexible* entered service in April 1985. All were built at Cherbourg Naval Dockyard. A larger SSBN of a completely new design is due to be laid down in 1988 for completion in 1994.



Below: Although of indigenous design, these submarines are similar in conception to the US Lafayette class, with the missiles housed in 16 launch tubes located abaft the fin.

Above and left: The first five units of the class carry a mix of M 2 and M 20 ballistic missiles (1). The two missiles are identical in appearance but the latter carries a larger 1MT thermo-nuclear warhead. The sixth unit, *L'œinflexible* has the M 4, a larger missile with greater range and a multiple-warhead capability. There are 16 vertical launch tubes in two rows of eight. A mix of L 5 Mod 3 antisubmarine torpedoes (2) and F 17 dual-purpose torpedoes can be fired from the four 21.7in (550mm) bow torpedo tubes.

Los Angeles class

Origin: USA, first unit completed 1976
Type: Attack submarine, nuclear-powered (SSN)
Displacement: 6,080 tons surfaced; 6,927 tons submerged
Dimensions: Length 360ft (109.8m); beam 33ft (10.1m); draught 32ft 4in (9.8m)
Propulsion: One S6G pressurized water-cooled reactor driving geared steam turbines; one shaft; 30,000shp for 31kt max
Complement: 127
Background: In the late 1960s the US Navy became increasingly concerned about the threat to its carrier battle groups posed by the new generation of Soviet submarines, and in particular the Charlie-class SSGN with its SS-N-7 'pop-up' missile. The most effective counter to Soviet tactics would be to station attack submarines ahead of the battle group to detect the Soviet missile boats as they took up their attacking stations: thus was born the 'close support' mission which provided the rationale for the development of the Los Angeles class. The ability to operate in conjunction with the carrier battle groups required high tactical speed, which in the Thresher/Permit and Sturgeon classes had been sacrificed in favour of quiet operation. However, the new submarine would also need to be at least as quiet as its immediate predecessors in order to engage in underwater combat with the Soviet SSGNs. The result was an exceptionally large boat with double the reactor power of earlier types.

Design: The Los Angeles design marked the final transition from the 'airship' hull-form of the Albacore and Skipjack to the cylindrical configuration which is a feature of all recent US submarines. The cylindrical middle body is almost as efficient as a continuously curved hull, and is much easier to build. The S6G reactor is a modified version of the D2G reactor used to power missile destroyers since the early 1960s. It employs natural circulation at low power ratings to minimize pump noise, but circulation pumps have to be switched on at higher speeds. This fits well into the pattern of 'sprint and drift' operations implied in the close support mission. The large size of the submarine has facilitated the effective isolation of noise-generating machinery from the hull, and the Los Angeles is probably the world's quietest nuclear submarine. The fin is relatively small in relation to the overall size of the submarine, thereby reducing resistance. The ability to rotate the fin-mounted hydroplanes to the vertical has, however, been sacrificed, placing limitations on under-ice operations. Later boats will have bow-mounted hydroplanes.
Armament: By the time the Los Angeles class entered service in the late 1970s the Mk 48 torpedo was in full production and had replaced virtually all the earlier types. The first 12 units received the Mk 113 fire control system and could therefore handle the SUBROC nuclear-tipped antisubmarine missile. Later units with the Mk 117 system could not handle SUBROC, but the Mk 117 is now being modified to make this possible. From 1978 onwards submarines of this class began to receive the Harpoon anti-ship missile. The trend towards tube-launched missiles continued with the first operational installation of the Tomahawk missile in 1983. Tomahawk (BGM-109), unlike Harpoon, was designed to be fired from a torpedo tube. It has a length of 20ft 3in (6.2m) and a diameter of 21in (533mm). It is powered by a turbojet sustainer motor with a solid-fuel booster and has a maximum range of 1,400nm (2,600km) in the land attack (TLAM) version, and 250nm (460km) in the anti-ship (TASM) version. The torpedo capacity of the Los Angeles class is no greater than that of the Sturgeons, although handling has been improved by the adoption of power transfer systems. The proliferation of tube-launched anti-ship missiles, allied to the retention of SUBROC, has resulted in difficult decisions regarding the appropriate weapon mix for a particular deployment. Later units of the class will therefore receive 15 vertical launch tubes for Tomahawk, located in the space between the bow sonar and the forward end of the pressure hull. Earlier units will eventually receive 12 similar tubes at scheduled refits.
Electronics: The Los Angeles class was designed from the outset to accommodate the BQQ-5 sonar suite. Like the BQQ-2 system

Right: The four midships 21in (533mm) torpedo tubes can fire the complete range of tube-launched weapons currently in service: the SUBROC antisubmarine missile (1), the Sub-Harpoon anti-ship missile (2), the dual-purpose Mk 48 torpedo (3), and the TLAM and TASM variants of the Tomahawk missile (4). Stowage capacity is currently limited to about 24 weapons, so later units of the class will carry their Tomahawk missiles in separate launch tubes.

USS *Los Angeles* (SSN 688)

which it replaces, the BQQ-5 is based on a large active passsive spherical bow sonar, a conformal passive hydrophone array, and a PUFFS fire control system. The BQS-11/12/13 spherical bow array incorporates Digital Multi-Beam Steering (DIMUS), which has superseded the mechanical scanning employed with earlier sonars and makes possible multi-target tracking. Another new feature of the BQQ-5 sonar suite is the addition of a towed array, which is stowed in a tube running along the hull casing. The model currently being fitted is the BQR-23 Submarine Towed Array Sonar System (STASS). Later submarines of the class will receive the Submarine Advanced Combat System (SUBACS), a new-generation integrated weapons/sonar control suite.

Construction: Thirty-four submarines of the Los Angeles class had been completed by the end of 1986, and a further 24 were under construction or on order, making this the largest class of nuclear submarine ever built.

Above: *Salt Lake City* (SSN 716) depicted during sea trials in 1984. The prominent fairing which runs the length of the casing houses the towed array, the winch being located between the bow and the forward end of the pressure hull. Note also the cylindrical hull-form, adopted in part to facilitate construction.

Below: A close-up of *Honolulu* (SSN 718). The small sail was adopted to minimize drag. Later boats will have 15 vertical-launch tubes for Tomahawk missiles fitted in a new section inserted between the bow and the forward end of the pressure hull.

Näcken class

Origin: Sweden, first unit completed 1980
Type: Attack submarine, diesel-powered (SS)
Displacement: 1,030 tons surfaced; 1,125 tons submerged
Dimensions: Length 162ft 6in (49.5m); beam 20ft (6.1m); draught 13ft (4.1m)
Propulsion: Diesel-electric drive on one shaft; one MTU 16V652 diesel generator; one Jeumont-Schneider electric motor; 1,800bhp for 20kt surfaced, 1,500hp for 20kt submerged
Complement: 19
Background: During the 1950s the Swedish Navy began the development of a series of small submarines of modern design intended for operations in the shallow waters of the Baltic. The primary mission of the early boats was anti-surface, but in recent years the anti-submarine mission has assumed greater importance, and the latest designs incorporate modern sensors, sophisticated noise reduction techniques, and both long (anti-ship) and short (ASW) torpedo tubes. The five submarines of the Sjöormen class, completed 1967-69, introduced the 'Albacore' hull-form and 'X'-planes to the Swedish Navy. They were followed by the three submarines of the Näcken class, an improved design developed following detailed design studies using computer analysis. Slightly smaller than their immediate predecessors, the Näckens featured a heavier torpedo armament and a new generation of automated machinery control and AIO/fire control systems.
Design: The Näcken is of single-hull construction with a prominent deck casing. The pressure hull, which is of high-yield steel, is cylindrical with a truncated cone aft. It is closed by flat bulkheads fore and aft, and there is a third pressure-tight bulkhead amidships, just abaft the fin. The internal layout is notable for its economical use of space. By shifting all batteries into the machinery spaces in the after part of the boat the designers have created a two-deck layout forward. The upper level houses the attack centre, which is immediately beneath the fin, and the accommodation spaces, which extend to the forward bulkhead. The torpedo tubes are on the lower level, with an extensive stowage and handling room abaft them. The machinery spaces are divided into three compartments. The forward compartment, which is on two levels, houses the highly-automated machinery control room and switchboard, with the 168-cell Tudor battery bank beneath. The centre compartment is also on two levels, with the single MTU diesel beneath and the auxiliary

Below: *Najad*, the second unit of the Näcken class, running on the surface. These compact submarines are of modern design throughout, and are ideally suited to the confined and shallow waters of the Baltic Sea.

Right: Näcken class boats have six bow tubes for 21in (533mm) torpedoes and two tubes for 16in (400mm) torpedoes. The current 21in torpedo is the Tp 61 (1), a high-performance anti-ship model which uses high-test peroxide propulsion. The short ASW torpedo fired from the 400mm tubes is the Tp 42, now being superseded by the Tp 43 (2).

***Näcken* (Näk)**

machinery above. The after compartment contains the main electric motor, which is a double-armature model by Jeumont-Schneider. The unusually high maximum speed of 20 knots on the surface enables these boats to make rapid transits in Swedish waters to meet any threat. Considerable attention has been paid to shock resistance and to silencing. The batteries and all propulsion and auxiliary machinery are on resilient mountings and have flexible couplings. The Swedish Navy was the first to adopt 'X'-planes operationally. They provide redundancy and fine control in both the horizontal and vertical planes, and an additional attraction for the Swedes was that they permitted 'bottoming' in the shallow waters of the Baltic. Somewhat surprisingly, the forward hydroplanes are mounted on the fin, as on the much larger US Navy SSNs. One unit of the class is being fitted with a Sterling closed-cycle engine.

Armament: Modern Swedish submarines have a mix of long anti-ship and short ASW torpedo tubes. In the Näcken class there are two horizontal banks of tubes, with reloads stowed abaft each tube.There are six positive discharge tubes of 21in (533mm) diameter for the Type 61 anti-ship torpedo, and two short 16in (400mm) tubes for the Type 42 anti-submarine torpedo. The swim-out method is employed for the latter to save space and provide for silent discharge. The Tp 61, which entered service in 1977, is a high-performance heavyweight torpedo with thermal (HTP) propulsion, capable of speeds in excess of 60 knots. It is wire-guided, and has a length of 23ft (7.1m) and a maximum range of 33,000yds (30,000m). The Tp 42 is a short (8ft 6in/2.6m) wire-guided acoustic-homing torpedo. The current Tp 422 model entered service in 1983, and will be superseded by the improved Tp 431 from 1987 onwards. FFV mines can also be launched from the torpedo tubes.

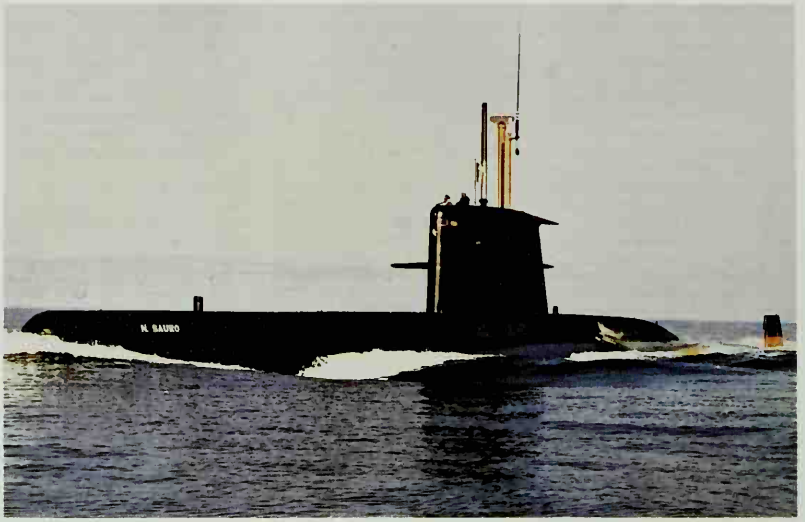
Electronics: The main active/passive attack sonar, which comprises a circular array of hydrophones, is located in the upper part of the bow casing, and may be a variant of the Krupp-Atlas CSU-3. The mast-mounted sensor outfit is unusual in that there is only a single Kollmorgen periscope for the search and attack functions. The Ericsson IDPS central data system, based on two Censor 932 computers, provides not only tactical data but also monitors the status of the machinery. The PEAB fire control system, which features two interchangeable consoles to provide tactical display and weapons control, allows the simultaneous tracking and engagement of multiple targets.

Construction: Three submarines of the Näcken class were completed between 1980 and 1981 at the Karlskrona and Kockums (Malmö) Shipyards.

Above: Three contemporary Swedish submarine types are featured in this photo. *Näcken* is outboard of *Sjöhunden* of the Sjöormen class, with *Vargen* of the older Draken class alongside the minelayer *Älvsborg*, which doubles in peacetime as a submarine tender. In the foreground is the stem of the first of four A-17 (Västergötland) class boats.

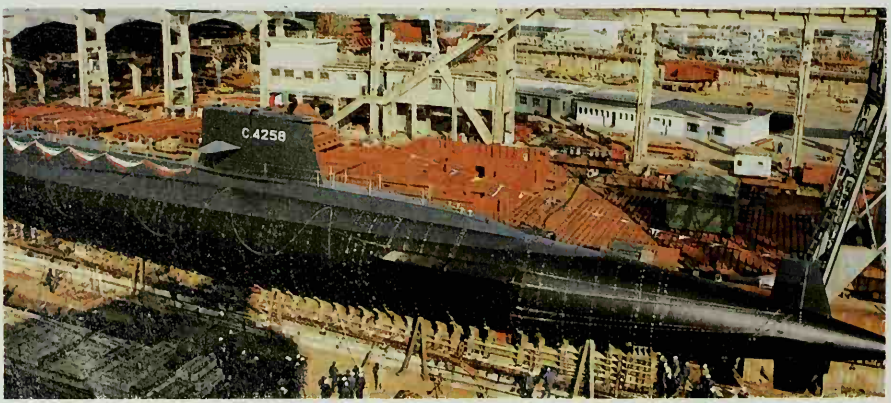
Nazario Sauro class

Origin: Italy, first unit completed 1980
Type: Attack submarine, diesel-powered (SS)
Displacement: 1,460 tons surfaced; 1,650 tons submerged
Dimensions: Length 209ft 6in (63.9m); beam 22ft 5in (6.8m); draught 18ft 9in (5.7m)
Propulsion: Diesel-electric drive on one shaft; three GMT A210 16 diesel generators, each 1070bhp; one Marelli electric motor; 3,210bhp for 14kt surfaced, 3,650hp for 20kt submerged
Complement: 49
Background: This was the second of Italy's postwar submarine designs. The first, the Toti, was a small coastal design comparable to the German Type 205/206. The Staff Requirements for the Nazario Sauro were for a larger boat with better endurance and improved habitability, capable of penetrating into waters controlled by a potential enemy. Operational conditions in the Mediterranean favoured a relatively small hull



Above: *Nazario Sauro*, the name-ship of the class. These submarines are a handy size for operations in the shallow waters of the Mediterranean; high underwater speed and good manoeuvrability were primary requirements for the design.

Below: A Sauro-class submarine under construction at the Monfalcone Yard of Fincantieri. Note the slim, tapered hull which is a feature of this class. The single pressure hull is topped by a prominent casing, while abaft the modern cruciform tail surfaces is a single, seven-bladed propeller. The forward hydroplanes are mounted on the fin, in the manner of US Navy submarines.



with high underwater speed and good maneouvrability, and further requirements were for a deep-diving capability, to take advantage of the thermal layers which plague sonar operations in the Mediterranean, and a low noise level. The first two units of the class were initially ordered in 1967, but budgetary problems resulted in cancellation and they were not reordered until 1972. Orders for a second pair were subsequently placed in 1976, but the completion of the first two units was again delayed because of defective batteries. This problem was finally resolved by purchasing batteries direct from Sweden, and a third pair with an improved weapon/sensor outfit was ordered in 1983.

Design: The Sauros have a modern 'tear-drop' hull-form with a single shaft and cruciform after control surfaces. The forward hydroplanes are mounted on the fin in the manner of US Navy SSNs, and single-hull construction was adopted to economise on weight. The pressure hull, which is cylindrical in the forward half of the boat but is tapered abaft the fin, is constructed of high-yield HY80 steel, giving these submarines a maximum diving depth in excess of 820ft (250m). It is closed at either end by hemispherical bulkheads. Beneath the fin there is a two-deck layout, with the control room and officer accommodation on the upper level, and the lower level occupied largely by the two 148-cell battery banks. Accommodation for the crew is located in the torpedo stowage room forward. The machinery spaces are divided into three sections. The forward compartment houses the three diesel generators, which are mounted abreast on a resiliently-mounted raft. The centre compartment houses the electrical switchboard with the auxiliary machinery beneath, and the after compartment is occupied by the large Marelli double-armature motor. The latter is air-cooled, and can produce 4,200hp for short periods. A speed of 19.3 knots was sustained for one hour on trials. Considerable attention was paid to silencing and shock resistance: not only is all machinery resiliently mounted, but there are flexible pipe connections and the machinery compartments are lined with noise-absorbent material, and the slow-turning seven-bladed propeller reduces cavitation at higher speeds. The snort tube has a particularly small cross-section and was designed to offer a low radar signature.

Armament: The submarines of the Nazario Sauro class have six bow tubes of standard 21in (533mm) diameter. Positive discharge enables them to fire torpedoes at maximum depth, and there is stowage for six reloads. The current Italian heavyweight torpedo is the Whitehead A.184, which is 19ft 8in (6m) long and can be fired against surface ships or submarines. The A.184 employs electric propulsion and is wire-guided, with an advanced active/passive acoustic homing head which controls both course and depth. A fast, 50-knot torpedo is currently under development: designated the A.290, it employs a lithium battery and a homing head developed from the short A.244 antisubmarine torpedo. In place of each torpedo, these submarines could carry two mines of the VS SM600 type. The VS SM600 is a sophisticated influence mine which can recognise the magnetic, acoustic and pressure signatures of a variety of surface ships and submarines. The fifth and sixth boats of the class will have longer tubes to enable them to fire the Sub-Harpoon anti-ship missile.

Electronics: The first four boats have the ELSAG/USEA IPD-70 sonar, which comprises a circular active/passive transducer with integral underwater telephone and passive intercept sonar, together with an ELSAG/USEA MD-100S conformal flank array. Mast-mounted sensors include Kollmorgen search and attack periscopes, the SMA SPS-704 radar, and ELT-724S passive ESM. The SEPA CCRG weapon control system can track four targets simultaneously. The fifth and sixth boats will have a more advanced electronics outfit based on the IPD-70S fully integrated sonar system.

Construction: The first four units of the Nazario Sauro class were completed by C.R.D.A., Monfalcone, between 1980 and 1982. The fifth and sixth units are being built by Fincantieri, the state-owned concern which has taken over the yard.

Below: The Sauros have six bow tubes of 21in (533mm) diameter. The current heavyweight torpedo is the Whitehead A.184 (1), a wire-guided weapon which can be fired against both surface ships and submarines. It will eventually be replaced by a 50-knot torpedo currently under development, the A.290. The fifth and sixth boats of the class will be fitted with longer tubes to enable them to fire the Sub-Harpoon anti-ship missile. In addition to the six weapons carried in the tubes there is stowage for six reloads; alternatively, two VS SM600 multi-sensor influence mines (2) can be carried in place of each torpedo.

Nazario Sauro (S 518)

Oberon class

Origin: United Kingdom, first unit completed 1960
Type: Attack submarine, diesel-powered (SS)
Displacement: 2,080 tons surfaced; 2,450 tons submerged
Dimensions: Length 290ft (88.5m); beam 26ft 6in (8.1m); draught 18ft 3in (5.6m)
Propulsion: Diesel-electric drive on two shafts; two ASR 16VVS-AS21 diesel generators, each 1,840bhp; two English Electric electric motors, each 3,000hp; 3,680bhp for 12kt surfaced, 6,000hp for 17kt submerged
Complement: 64
Background: Work on the first postwar British production submarine design, the Porpoise class, began in 1949. Like other contemporary western designs, it was heavily influenced by the German Type XXI. Draft staff requirements called for a speed of 17 knots to be sustained for 20 minutes, and for a maximum diving depth of 650ft (200m). The new submarines were designed for the ASW patrol mission, and featured a pair of stern tubes for short antisubmarine torpedoes. The Porpoise design proved particularly successful, and was succeeded by a modified design, the Oberon, which although virtually indistinguishable externally, incorporated a number of detail improvements.
Design: The Oberon has the conventional double-hull

Above: Although now more than 20 years old, the Oberons, represented here by *Otus*, continue to set a standard for quiet operation in the Royal Navy which only the very latest nuclear boats have exceeded. The Oberon design is essentially traditional, with a cigar-shaped hull flanked by ballast tanks, but they are large boats with good long-range performance on the surface, and have acquired a high reputation in service.

Above and right: The Oberons have six bow tubes of 21in (533mm) diameter, plus two shorter stern tubes of the same diameter. When these submarines were first completed in the 1960s they carried the Mk 8 anti-ship torpedo and the Mk 20(S) short anti-escort torpedo; the latter was fired from the stern tubes. From about 1970 the Mk 20 was replaced by the Mk 23 antisubmarine homing torpedo (1), which employed wire guidance. The Mk 23 was in turn superseded by the Mk 24 Tigerfish (2), a 'long' torpedo which can be fired only from the bow tubes of the Oberon. The stern tubes are therefore no longer used.
Dual-purpose variants of Tigerfish were to have replaced the elderly Mk 8 torpedo, whose design dates back to the 1930s, but the latter remained in service in the late 1980s.

configuration of prewar British submarines. Advanced high-yield UKE steel was used in the construction of the pressure hull. In contrast, lightweight materials were used extensively in the construction of the fin and casing: the first unit completed, Orpheus, had a fin made of aluminium, but glass-fibre laminate was adopted for later boats. The long, single-cylinder pressure hull allows for a single-deck layout with the control room positioned centrally. Forward of the control room are the accommodation spaces, with the batteries beneath, and abaft it are the machinery spaces. US-type 'Guppy' batteries were adopted in order to simplify wartime supply. They are located in two compartments, each with 224 battery cells, and are linked in series to give 880v for short bursts. Not only did the Porpoise and Oberon types easily attain their designed underwater speed, but they have proved to be exceptionally quiet. A maximum range of 9,000nm (16,700km) on the surface enables them to undertake distant deployments, and although their primary patrol area is the North Atlantic, submarines of the class have regularly deployed to the Falkland Islands since the conflict of 1982.

Armament: The Oberons have six 21in (533mm) bow tubes, and two shorter tubes of the same diameter in the stern. When they were completed in the 1960s, they carried the Mk 8 anti-ship torpedo and the Mk 20(S) antisubmarine torpedo. The Mk 8, which is 22ft (6.7m) long, was designed in the 1930s but has proved so reliable that it was reported to be still in service in 1986. It is a straight-running weapon with a range of 5,000yds (4,500m) at a speed of 45 knots. The Mk 20 was developed in the 1950s as an anti-escort weapon and was designed to be fired from the stern tubes of the Porpoise and Oberon classes. It employed passive acoustic homing, was 13ft 6in (4.1m) long and had a range of 12,000yds (11,000m) at 20 knots. The Mk 20 was superseded from 1970 onwards by the Mk 23, which was essentially a Mk 20 with an additional section incorporating a wire-guidance casket. During the late 1970s both the Mk 20 and the Mk 23 began to be replaced by the Mk 24 Tigerfish (see Swiftsure). Tigerfish, unlike its predecessors is a long torpedo and has to be fired from the bow tubes of the Oberon. The short stern tubes are therefore no longer used.

Electronics: The original sonar outfit of the Oberons comprised a Type 187 active/passive scanning sonar, housed in a prominent dome above the bow, a Type 186 passive conformal flank array, and a Type 197 intercept array located at the after end of the fin. Type 186 was subsequently replaced by Type 2007, but the original sonar outfit remained otherwise unchanged into the 1980s. The decision to update these submarines with modern sonars was forced on the Royal Navy by delays in the Type 2400 (Upholder) programme. Nine boats are now to be retro-fitted with the Type 2051 Triton integrated sonar suite, which uses off-the-shelf equipment developed commercially. A new electronically-scanned active/passive array is housed in a streamlined sonar dome, and the suite includes a Type 2046 'clip-on' towed hydrophone array. The DCH tactical data system incorporates the latest compact computers with M700/40 microprocessors, and the fire control system will allow for simultaneous firing of two Mk 24 Tigerfish torpedoes. MEL Manta electronic warfare intercept equipment will be fitted.

Construction: Thirteen submarines of the Oberon class were completed for the Royal Navy between 1960 and 1967 and a further 14 have been built in British shipyards for other countries: three for Canada (completed 1965-68), six for Australia (1967-78), three for Brazil (1973-77) and two for Chile (1976). The Australian and Canadian boats are currently being refitted with new sensors, largely of US origin.

Above: *Oppossum* was the first of the British Oberons to receive the Type 2051 Triton integrated sonar, which is currently being fitted to a further eight boats of the class. The modernisation will include provision of a Type 2046 clip-on towed array and new fire control and electronic warfare systems. The remaining four unmodernised units are scheduled for disposal.

Oberon class (unmodernised)

2

Ohio class

Origin: USA, first unit completed 1981
Type: Ballistic missile submarine, nuclear-powered (SSBN)
Displacement: 16,764 tons surfaced; 18,750 tons submerged
Dimensions: Length 560ft (170.7m); beam 42ft (12.8m); draught 36ft 6in (11.1m)
Propulsion: One S8G natural circulation reactor with turboeducation drive; one shaft; 60,000shp for 20+kt
Complement: 160
Background: The original requirement for the Ohio class came from a need to replace the SSBNs of the George Washington and Ethan Allen classes, which were incapable of conversion to fire the current Poseidon or the projected Trident missiles, and which by the early 1980s would be more than 20 years old. There was by the early 1970s concern regarding the dramatic growth in Soviet antisubmarine capabilities, which threatened many of the SSBN patrol areas favoured by the US Navy. Forward deployment from European bases, which exposed the US SSBNs to preemptive attack in wartime and to terrorist attack in peacetime, was also increasingly questioned. The Trident C-4 missile which was developed as a successor to Poseidon therefore featured a significant increase in range to 4,000+nm (7,400km). Available sea-space for SSBN patrol operations was thereby extended from three million to fourteen million square miles, and submarines armed with the missile would no longer have to operate from forward bases in order to target the major cities of the Soviet Union. Initially the new SSBN design was to have been an enlarged and improved Lafayette, employing the same S5W reactor for a maximum speed of only 19-20 knots. However, the US Navy was anxious to install a natural circulation reactor based on the model being tested in the *Narwhal* (SSN 671). The desire for sophisticated noise reduction techniques led in turn to a proposal that the expense involved in efficient quieting could be better justified if the missile complement was raised from the original 16 to 24. The result was a submarine more than twice the size of the Lafayette, with a 60,000shp reactor.
Design: The size of the Ohio was determined by the number of missiles to be carried. More than 24 would have made for too long a hull, with adverse consequences for the manoeuvrability of the submarine. The missile tubes are of larger diameter than those of the Lafayette to enable the Ohios to fire the Trident D-5 missile when the latter enters service in the late 1980s. The hull-form, like that of the Los Angeles, is essentially cylindrical for ease of construction. The propulsion machinery is extremely quiet in operation. The large S8G natural circulation reactor drives two sets of turbines, one for high and the other for low speed, via a turboeduction drive system. All noise-emitting machinery is raft-mounted and isolated from the hull. Sonar capabilities were accorded a higher priority than in earlier SSBNs, and the Ohios have a similar arrangement to that of US Navy SSNs, with a large spherical bow array complemented by amidships torpedo tubes. The large size of the hull has made possible a four-deck layout beneath the fin, with space for storage batteries below.
Armament: The Trident I C-4 missile has a length of 34ft (10.4m) and a diameter of 6ft 2in (1.9m). It comprises a three-stage solid-fuel rocket carrying eight 100kT MIRVed nuclear warheads. Since 1980 some missiles have had an alternative payload comprising eight Mk 500 Evader MaRVs (Manoeuvrable Reentry Vehicles) developed by Lockheed. Towards the end of the decade the Trident I C-4 will be superseded by the Trident II D-5 missile currently under development. The D-5 is a much larger missile than the C-4, with a length of 45ft 6in (13.9m) and a diameter of 6ft 11in (2.1m). Range will be a massive 6,000nm (11,100km) and a CEP of only 400ft (120m) is projected. The D-5 will carry up to 14 MIRVs of 150kT each, with an alternative payload of seven 300kT MaRVs. The four Mk 68 21in (533mm) torpedo tubes, which are located directly

Above: The Ohios are the largest submarines ever built in the West, and at 18,750 tons submerged displacement they are more than twice the size of their predecessors of the Lafayette class. They also are quieter, have more sophisticated sensors, and carry eight more ballistic missiles than earlier SSBNs.

Right: The Ohios have 24 vertical launch tubes for ballistic missiles disposed in two rows abaft the fin. The missile currently carried is the Trident I C-4 (1), which has a range of more than 4,000nm (7,400km) and can carry up to eight independently-targeted reentry vehicles. In the late 1980s the C-4 will be superseded by the Trident II D-5 misile, which will carry up to 14 MIRVs and have a range of 6,000nm (11,100km). The launch tubes of the Ohios have been designed to accommodate the larger D-5 missile without modification. The four 21in (533mm) torpedo tubes are located directly beneath the fin, and fire the Mk 48 dual-purpose torpedo (2).

beneath the diminutive fin, fire the Mk 48 high-performance torpedo. As with the Los Angeles class, the torpedo transfer system is fully automated.

Electronics: The BQQ-6 sonar suite is similar to the BQQ-5 suite installed in the most recent SSNs, but without the active component. It comprises a spherical BQS-13 passive ranging sonar for fire control, a BQR-25 conformal hydrophone array, a PUFFS spot hydrophone array for fire control, and a BQR-23 towed array. There is also a BQS-15 sonar for under-ice operation, and a BQR-19 side-looking sonar for bottom-mapping. The Ohios have two Mk 2 SINS (Ship's Inertial Navigation System), and are fitted to receive data from navigation satellites to ensure that their missiles are accurately targeted. Missile fire control is provided by the Mk 98 digital computerized FC system, and the Mk 118 system is installed for torpedo fire control. The surveillance radar is a BPS-15A, and the WLR-8 (V) electronic warfare system is fitted.

Construction: *Ohio* (SSBN 726), the name-ship of the class, was completed three years late. Since that time, however, a further seven submarines of the class have been completed and the programme is now on schedule. Six units of the class are under construction or on order, and a four more are projected. All have been built by General Dynamics, Groton.

Above: *Florida* (SSBN 728), the third of eight Ohio-class SSBNs already in service; six further units are under construction, and four more are projected. They are the only US submarines capable of carrying the Trident II D-5 missile, which is significantly larger than its predecessors and will have a range of 6,000nm.

USS *Ohio* (SSBN 726)

Oscar class

Origin: USSR, first unit completed 1980
Type: Cruise missile submarine, nuclear-powered (SSGN)
Displacement: 11,000 tons surfaced; 13,500 tons submerged
Dimensions: Length 470ft (143m); beam 60ft (18m); draught 36ft (11m)
Propulsion: Two pressurized water-cooled reactors driving geared steam turbines; 2 shafts; 60,000shp for 25kt max
Complement: 130
Background: The Oscar is effectively a replacement for the ageing Echo-class submarines of the 1960s, and like its predecessor it is designed primarily for anti-carrier operations in sea areas relatively close to the Soviet Union. Its mission is to take up an advance position in the path of a US Navy carrier battle group, and to launch a multi-missile strike at maximum range. This would be coordinated with similar strikes by long-range maritime bombers and surface units in an attempt to saturate the defences of the carrier battle group. Initial target data would be provided by satellites or reconnaissance aircraft, creating a requirement for secure communications with a central command post ashore. Unlike the SS-N-3/12 missiles carried by the Echo, the SS-N-19 which equips the Oscar can be fired from beneath the surface. The submarine is therefore far less vulnerable to detection and preemptive attack.
Design: The Oscar is an exceptionally large boat, with a submerged displacement between two and three times that of contemporary Western nuclear-powered attack boats. The launch tubes for the 24 SS-N-19 missiles are located between the inner and outer hulls in the forward half of the submarine: there are six large rectangular hatches, each about 23ft (7m) long and concealing two missile tubes, on either side of the fin. The tubes are thought to be angled at approximately 45 degrees to the vertical. The outer hull casing is almost square in cross-section throughout the missile section, and there is a stand-off of about 13ft (4m) between the inner pressure cylinder and the outer casing. Abaft the missile section the outer hull tapers sharply, terminating in conventional cruciform after control surfaces. The second and third boats of the class have a more angular rudder-fin topped by a tubular housing for a towed communications array. The forward hydroplanes are close to the bow, as in the Typhoon, and are fully retractable. There is some disagreement as to the precise nature of the propulsion plant: because of the amount of space taken up by the SS-N-19 missile tubes, the pressure hull is relatively small in diameter (between 30ft and 36ft, 9-11m); a single large reactor is therefore unlikely. The length of the after section of the submarine suggests that two reactors are installed in series on the centre-line, with two sets of turbines driving two seven-bladed propellers. A total of 60,000shp would suffice to drive the Oscar at a speed of around 25 knots, which would be adequate for the projected mission of these submarines, given that they would take up position in advance of a task force and that noisy, high-speed operation on the flanks would therefore be unnecessary. As with other contemporary Soviet submarines, anechoic tiles have been applied over the entire hull casing.
Armament: The SS-N-19 anti-ship missile – the same model that equips the large nuclear-powered cruisers of the Kirov class – has a conventional aeroplane configuration, with folding wings for stowage in the launch tubes, and artists' impressions produced in the West show a turbojet sustainer motor slung under the missile fuselage flanked by twin solid-fuel boosters. The SS-N-19 has a maximum range estimated at 240nm (450km). Length is probably around 33ft (10m), and alternative high explosive (HE) and nuclear payloads can be carried. Eight torpedo tubes,

Left: The Oscar is the largest SSGN yet built, and surpasses in size all but the latest ballistic missile submarines. Her immense beam was generated by the need to accommodate large-diameter vertical-launch tubes for SS-N-19 anti-ship missiles outside the single pressure hull on either side of the fin. The six large square port-side hatches are particularly prominent in this close-up of the first unit of the class. There are two missile tubes beneath each missile hatch.

Right: The main armament of the Oscar comprises 24 SS-N-19 anti-ship cruise missiles (1) which are fired from angled launch tubes abeam the fin. Eight torpedo tubes, of both the standard 21in (533mm) and the larger 26in (650mm) diameter, are fitted, and there is stowage for 16 reloads. Antisubmarine homing torpedoes (2) and the SS-N-15 nuclear-tipped ASW missile (3) can be fired from the 21in tubes, while the 26in tubes can handle the SS-N-16 conventional ASW missile (4) and the Type 65 wake-homing torpedo (5).

including both the standard 21in (533mm) model and the large-diameter 26in (650mm) model, are fitted. These can handle the complete range of contemporary Soviet tube-launched weapons, including the SS-N-15 and SS-N-16 antisubmarine missiles.

Electronics: A large active/passive low-frequency bow sonar is fitted, together with an active medium-frequency ranging sonar; there are also passive arrays along the length of the hull. A single pair of large rectangular hatches immediately abaft the fin house buoys for VLF communications, and the second and third boats of the class also have a towed array for VLF (ELF?) communications which is deployed from the small tubular housing atop the vertical stabilizer. The low, streamlined fin houses an extensive array of masts including Snoop Pair/Rim Hat (surface surveillance/ESM), Park Lamp (VLF/LF reception), Pert Spring (satellite navigation) and Shot Gun (VHF communications). There are also numerous electro-optical sensors, including the Cod Eye radio sextant.

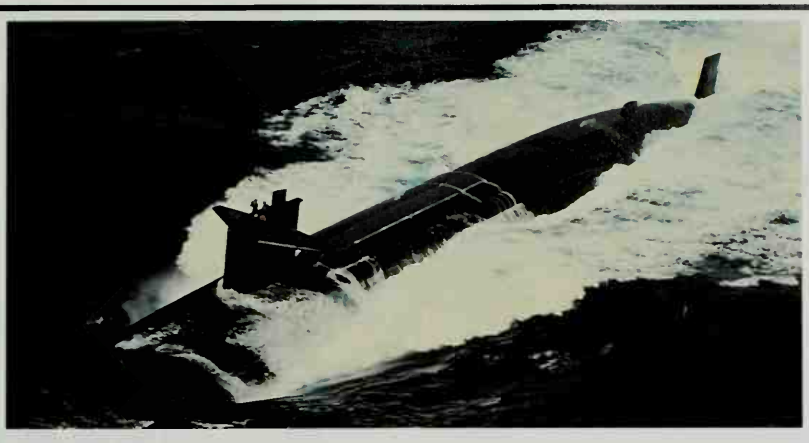
Construction: The first unit of the class was laid down at the Severodvinsk Shipyard in 1978, was launched in 1980, and ran her sea trials late in the same year. The second boat was not launched until 1982, and the third followed in 1985. Probably only the Severodvinsk Shipyard is capable of building submarines of this size, and although slow series production is proceeding, it seems unlikely that it will exceed a completion rate of one hull every two years.

Above: The second unit of the class photographed by the Norwegian Air Force in the area of the Soviet Northern Fleet. These large submarines would be deployed to counter US Navy Carrier Battle Groups. Note the distinctive tail-fin, topped by a cylindrical dispenser for a towed communications array.

Permit class

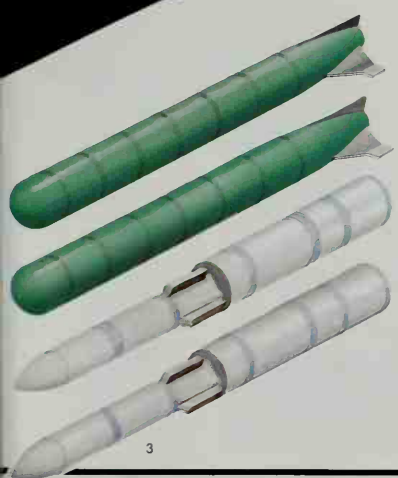
Origin: USA, first unit completed 1961
Type: Attack submarine, nuclear-powered (SSN)
Displacement: 3,750 tons surfaced; 4,300 tons submerged
Dimensions: Length 278ft 6in (84.9m); beam 31ft 8in (9.7m); draught 29ft (8.8m)
Propulsion: One S5W pressurized water-cooled reactor driving geared steam turbines; one shaft; 15,000shp for 27kt max
Complement: 106
Background: During the early 1950s US Navy tactical thinking favoured the parallel development of high-performance attack submarines for fleet work and slower hunter-killer submarines (SSKs) for deployment in antisubmarine barriers. A small experimental nuclear-powered SSKN, the *Tullibee* (SSN-597), was built to test the latter concept. The *Tullibee* employed turbo-electric propulsion for quietness, and was designed around a new sophisticated sonar suite, designated BQQ-1, which featured a large spherical bow sonar. This effectively displaced the torpedo tubes, which were relocated amidships. Even before the completion of *Tullibee*, however, it became apparent that the Navy could not afford two separate lines of development. The Thresher (now Permit) class which succeeded the Skipjacks was therefore biased heavily towards ASW, and a number of the systems developed for the *Tullibee* were incorporated.
Design: The Thresher was the first US Navy production submarine to have the revolutionary sonar/torpedo tube arrangement introduced by the *Tullibee*. This arrangement had the effect of minimising interference with sonar reception, and was adopted in all successive classes of US Navy SSN. First sketches of the design also show a turbo-electric propulsion plant, but the installation employed for the *Tullibee* produced insufficient power for a submarine the size of the Thresher, and a purpose-built plant would have taken too long to develop, so the US Navy persisted with the proven S5W reactor and conventional geared turbines. In the event a comparable level of quieting was achieved by isolating the propulsion machinery from the hull. The turbines and gearing were mounted on a 'raft' with resilient mountings. However, these measures had the effect of increasing the overall size of the submarine, and as the US Navy was by now committed to a reactor of fixed power, it would have to accept a loss of speed as compared with the Skipjack. Every effort was made to minimise this speed-loss. The size of the fin was reduced dramatically, so that it contributed only 8-10% of the total resistance of the submarine, as compared to 30% for the Skipjack. This resulted in problems in accommodating all the necessary sensor masts, and it was still not enough. Not until the Los Angeles class (qv) was the high speed of the original Skipjack design to be achieved again. The other innovation associated with the Thresher class was the use of HY80 steel in the construction of the single pressure hull. A maximum diving depth of 1,300ft (400m) is reported, but the introduction of high-yield steels was not without problems: the loss of the original name-ship of the class, Thresher (SSN-593), less than two years after her completion is thought to have been due to defective welding. However, improvements in construction techniques appear to have eliminated these problems in later boats of the class.
Armament: Because the bow position is occupied by the BQS-6 transducer array there are only four torpedo tubes, which are located beneath the fin and angled out at an angle of 10 degrees. The broad handling room can accommodate an estimated 18 torpedoes or missiles. As completed the Threshers were equipped to fire the Mk 14/16 anti-ship torpedo, the Mk 37 antisubmarine torpedo, and the Mk 45 ASTOR nuclear-tipped torpedo (see Skipjack). They were also designed from the outset to fire the SUBROC missile (see Sturgeon), which entered operational service in 1965. The earlier marks of torpedo have now been replaced by the dual-role Mk 48, and from 1976 onwards all units of the class were fitted to fire the Harpoon anti-ship missile.
Electronics: The BQQ-2 integrated sonar suite with which these submarines were initially fitted comprised the BQS-6 spherical active/passive array, the BQR-7 conformal passive array, and the BQG-3 PUFFS fire control sonar. The BQS-6 is capable of making detections out to the first convergence zone (30-35nm, 55-65km) using the bottom bounce or convergence zone modes of operation. The BQR-7 array comprises a 50ft (15m) triple row of 'spot' hydrophones for passive search and target classification. The BQQ-2 sonar suite is currently being replaced by the BQQ-5 (see Los Angeles). The original Mk 113 analogue fire control system has been replaced by the digital Mk 117 to enable the submarines to fire Harpoon. Mast-mounted sensors include search and attack periscopes, a BPS-15 surveillance radar, and the customary ESM and communications antennae.
Construction: Fourteen submarines of the Thresher/Permit class were completed at five different shipyards between 1961 and 1967. The last three units were built as prototypes for the succeeding Sturgeon class (qv), and have similar dimensions and displacement.

USS *Permit* (SSN 594)



Left: An overhead view of *Guardfish* (SSN 612). The Thresher/Permit class was the first operational US submarine type to be fitted with the BQQ-2 sonar suite. The cylindrical transducer for the active/passive BQS-6 array is located in the bow, and the four torpedo tubes are angled outboard beneath the fin. This revolutionary arrangement has been adopted in all subsequent attack submarines and SSBNs built for the US Navy.

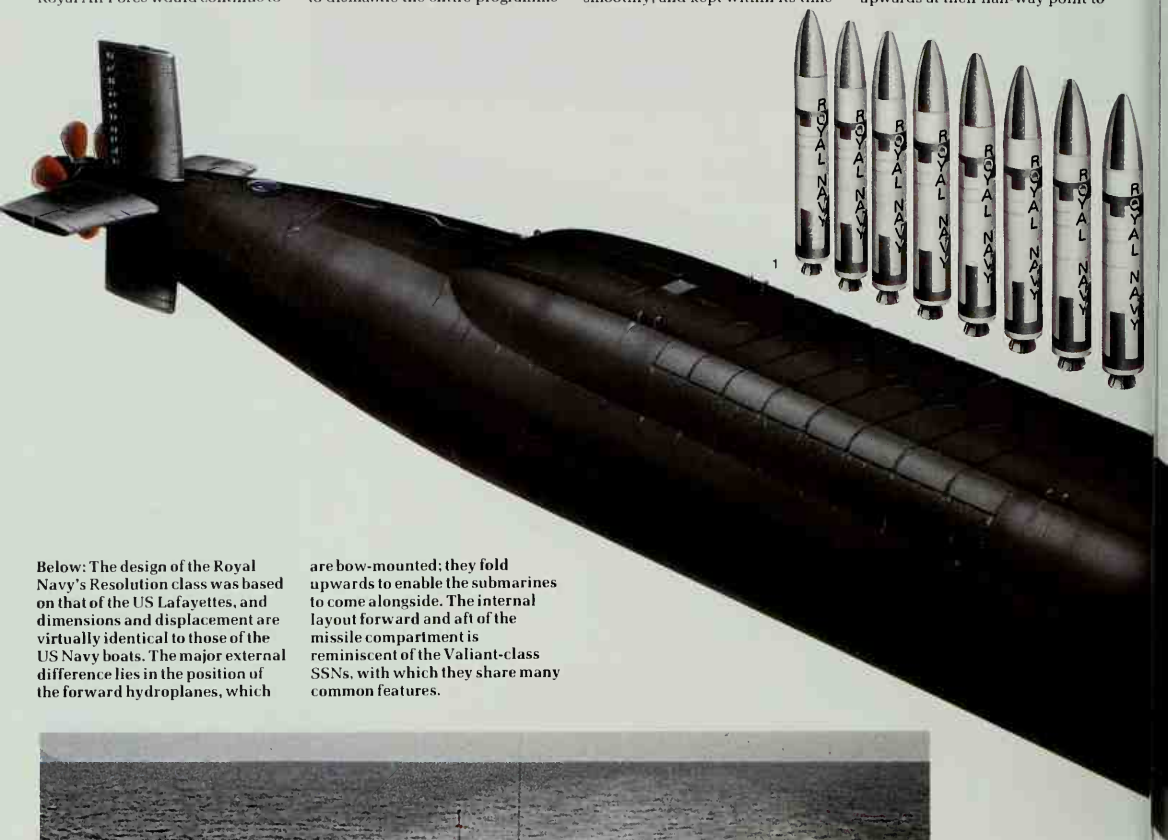
Below: A bow view of *Permit* (SSN 594), now the name-ship of the class. *Thresher* (SSN 593), the original name-ship, was lost with all hands less than two years after completion. Her loss was attributed to defective welding of the high-yield HY80 steel employed in the construction of her pressure hull. HY80 was adopted to give these submarines a maximum diving depth of 1,300ft (400m), and the welding problems have since been resolved.



Left: The submarines of the Permit class are fitted with four 21in (533mm) torpedo tubes angled out beneath the fin. They were designed from the outset to fire the SUBROC nuclear-tipped antisubmarine missile (1), fire control data being provided by the spherical EQS-6 sonar array which occupies the bow. During the 1970s the original mix of torpedoes was replaced by a homogeneous outfit of Mk 48 torpedoes (2), which can be fired against both surface ships and submarines. Since 1976 the Permits have undergone modification to enable them to fire the Sub-Harpoon anti-ship missile (3), which is canister-launched.

Resolution class

Origin: United Kingdom, first unit completed 1967
Type: Ballistic missile submarine, nuclear-powered (SSBN)
Displacement: 7,500 tons surfaced; 8,400 tons submerged
Dimensions: Length 425ft (129.5m); beam 33ft (10.1m); draught 30ft (9.1m)
Propulsion: One PWR 1 pressurized water-cooled reactor driving geared steam turbines; one shaft; 15,000shp for 24kt max
Complement: 143
Background: Until the early 1960s it had been envisaged that the Royal Air Force would continue to be responsible for the British nuclear deterrent. However, following the cancellation of the airborne Skybolt missile it was agreed at a joint Anglo-American conference at Nassau in 1962 that the United States would supply the Polaris missile system to the Royal Navy. After a careful study of refit schedules it was resolved that five submarines would be needed in order to guarantee at least one on patrol at all times. However, the fifth boat was cancelled by the Labour Government of 1964, which had entered office pledged to dismantle the entire programme and to complete those boats already laid down as attack submarines. The design was based on the US Navy's Lafayette class, but with British equipment and machinery. The Polaris A-3 missiles, the missile tubes, and the missile fire control systems were purchased directly from the United States. A special Polaris Executive was set up to supervise the construction of the SSBNs, and the creation of the necessary training and support facilities. In spite of its complexity the programme proceeded remarkably smoothly, and kept within its time schedule and projected cost.
Design: The Resolutions are generally similar in overall size and in appearance to the US SSBNs of the Lafayette class, the only major external difference being the location of the forward hydroplanes on the hull casing close to the bow. The British designers considered the adoption of fin-mounted planes, but maintained that the major advantage of better control at low speeds did not outweigh the disadvantages. The hydroplanes on the Resolution class fold upwards at their half-way point to



Below: The design of the Royal Navy's Resolution class was based on that of the US Lafayettes, and dimensions and displacement are virtually identical to those of the US Navy boats. The major external difference lies in the position of the forward hydroplanes, which are bow-mounted; they fold upwards to enable the submarines to come alongside. The internal layout forward and aft of the missile compartment is reminiscent of the Valiant-class SSNs, with which they share many common features.

Above and right: The Resolutions have 16 vertical launch tubes for the Polaris A-3TK missile (1), which has a range of 2,500nm (4,600km) and is now fitted with the British-developed Chevaline multiple warhead, comprising six reentry vehicles. There are six bow tropedo tubes of 21in (533mm) diameter, and the wire-guided Mk 24 Tigerfish torpedo (2) has now superseded the Mk 20/23 ASW torpedoes and the Mk 8 anti-ship torpedoes originally carried.

allow the submarine to come alongside. Internally, the layout forward and aft of the missile compartment is reminiscent of the SSNs of the Valiant class. The pressure hull is cylindrical throughout most of its length, and forward of the missile section there is a three-deck layout housing the control and accommodation spaces, terminating in a smaller cylinder containing the torpedo stowage room. The machinery spaces abaft the missile section are laid out in similar fashion to those of the Valiants (q.v.). However, the Polaris installation necessitated an increase in electrical generating power, so each of the two main turbo-alternators produces 1,700kW. As with the Valiants, a Paxman 4,000bhp diesel generator is available to provide emergency power in the event of reactor failure. During recent refits the noise signature of the auxiliary machinery has been reduced by 20%.

Armament: The Polaris A-3 missile has a length of 32ft 4in (9.85m) and a diameter of 4ft 6in (1.37m). It comprises a two-stage solid-fuel rocket with a maximum range of 2,500nm (4,600km) and was initially fitted with a single large nuclear warhead of British design. This is currently being replaced by six Chevaline multiple reentry vehicles (MRVs), each of around 150kT. Development was initiated in the early 1970s to improve penetration of Soviet missile defences around Moscow and the MRVs can hit targets 25 miles (40km) apart, but the all-British programme encountered serious technical difficulties and massive cost overruns. The first submarine to receive the improved missile (designated the A-3TK) was *Renown*, in 1982; *Resolution* followed in 1984, and *Repulse* in 1986. Work is now proceeding on re-motoring the missiles. In addition to their Polaris missiles the SSBNs of the Resolution class are fitted with six torpedo tubes of 21in (533mm) diameter. When first completed they carried the Mk 20 and Mk 23 antisubmarine torpedoes and the Mk 8 anti-ship torpedo, now replaced by the wire-guided Mk 24 Tigerfish.

Electronics: The original sonar outfit of the Resolution class was identical to that of the Valiants, with a Type 2001 active/passive chin array, a Type 2007 passive flank array, and a Type 197 sonar intercept array. Because of the decision to replace the Resolutions by four new Trident submarines of the Vanguard class beginning in the early 1990s, they will not have the Type 2001 array replaced by the Type 2020 sonar now being retrofitted in SSNs of the Valiant and Swiftsure classes. However, significant improvements have been made to the Action Information Organisation and Fire Control System, and the SSBNs have now been fitted with the Type 2019 intercept sonar and the Type 2024 towed hydrophone array. The latter was developed initially in collaboration with the United States and is based on the US BQR-15 towed array.

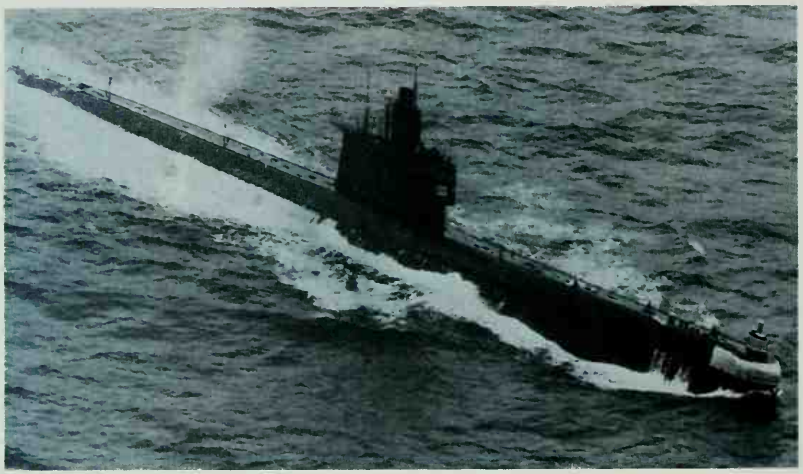
Construction: Four submarines of the Resolution class were completed between 1967 and 1968. Two were built by Vickers-Armstrong, Barrow-in Furness, and the other two by Cammell Laird, Birkenhead.

Above: **The Resolutions continue to carry the Polaris A-3 missile. Recent modifications include the incorporation of six Chevaline multiple reentry vehicles developed in the United Kingdom, and re-motoring of the missiles will extend their service life until the new Vanguard class, armed with the Trident II D-5 missile, enters service in the 1990s.**

Resolution class *Revenge* (S 27)

Romeo class

Origin: USSR, first unit completed 1958
Type: Attack submarine, diesel-powered (SS)
Displacement: 1,330 tons surfaced; 1,700 tons submerged
Dimensions: Length 254ft (77m); beam 22ft (6.7m); draught 16ft (4.9m)
Propulsion: Diesel/electric drive on two shafts; two Type 37D diesels, each 2,000bhp; two electric motors, each 1,500hp; 4,000bhp for 15.5kt surfaced, 3,000hp for 13kt submerged
Complement: 56
Background: The Romeo was designed in the mid-1950s as the natural successor to the medium-range Whiskey class, some 230 of which were completed between 1950 and 1957 to protect Soviet territory against the threat posed by the Western carrier task forces and amphibious landing fleets. The Romeo was essentially similar to the Whiskey in terms of its basic design, but would incorporate more advanced sensors. However, just as work on the first Romeos began there was a major change in Soviet naval policy. The defence of Soviet waters would henceforth be performed by submarines, surface craft and land-based aircraft armed not with torpedoes but with long-range cruise missiles. There was therefore no longer a requirement for a medium-range torpedo attack submarine, and construction of the Romeo was terminated after only 20 had been laid down. A number of the Soviet-built boats were transferred to friendly navies shortly after completion: six were delivered to Egypt 1966-69, two to Bulgaria 1971-72, and more recently two have been transferred to Algeria (1982-83) and two to Syria (1986). During the 1950s, however, the People's Republic of China was given access to the plans of the Romeo, and received sufficient technical assistance to begin construction. The first Chinese boat is reported to have been completed as early as 1960, but series production was established only in the 1970s because of technical and political problems. However, by the early 1980s more than 90 units had been completed, including a number for export.
Design: The hull-form of the Romeo, essentially that of the Whiskey, has the traditional 'cigar' shape common to most submarine types completed in the immediate postwar period. Control surfaces are also of conventional design, with twin propellers housed within circular propeller guards forward of horizontal hydroplanes and a single rudder. The forward hydroplanes retract into the upper part of the hull casing. The fin is also of similar size to that of the later Whiskeys, but there is a prominent fairing above it which houses the snorkel and the two periscopes and which serves to distinguish the Romeo from its predecessor. The major structural modification is to the bow, which has been redesigned to accommodate the Feniks passive sonar array and an additional pair of torpedo tubes. Internally, there are few changes. The single pressure cylinder allows for only one usable deck. The control room and the accomodation spaces are on the same level, with the batteries beneath. The machinery spaces comprise a main engine room housing the two Type 37D diesels, and a motor room housing the two electric motors. There are stowage rooms serving both the forward and the after torpedo tubes.
Armament: The Romeo has six bow and two stern torpedo tubes, all of 21in (533mm) diameter. In addition to the eight torpedoes carried in the tubes, an estimated six reloads can be accommodated. For an alternative payload each torpedo could be replaced by two mines. The standard torpedo employed by Soviet-built units is almost certainly an elderly

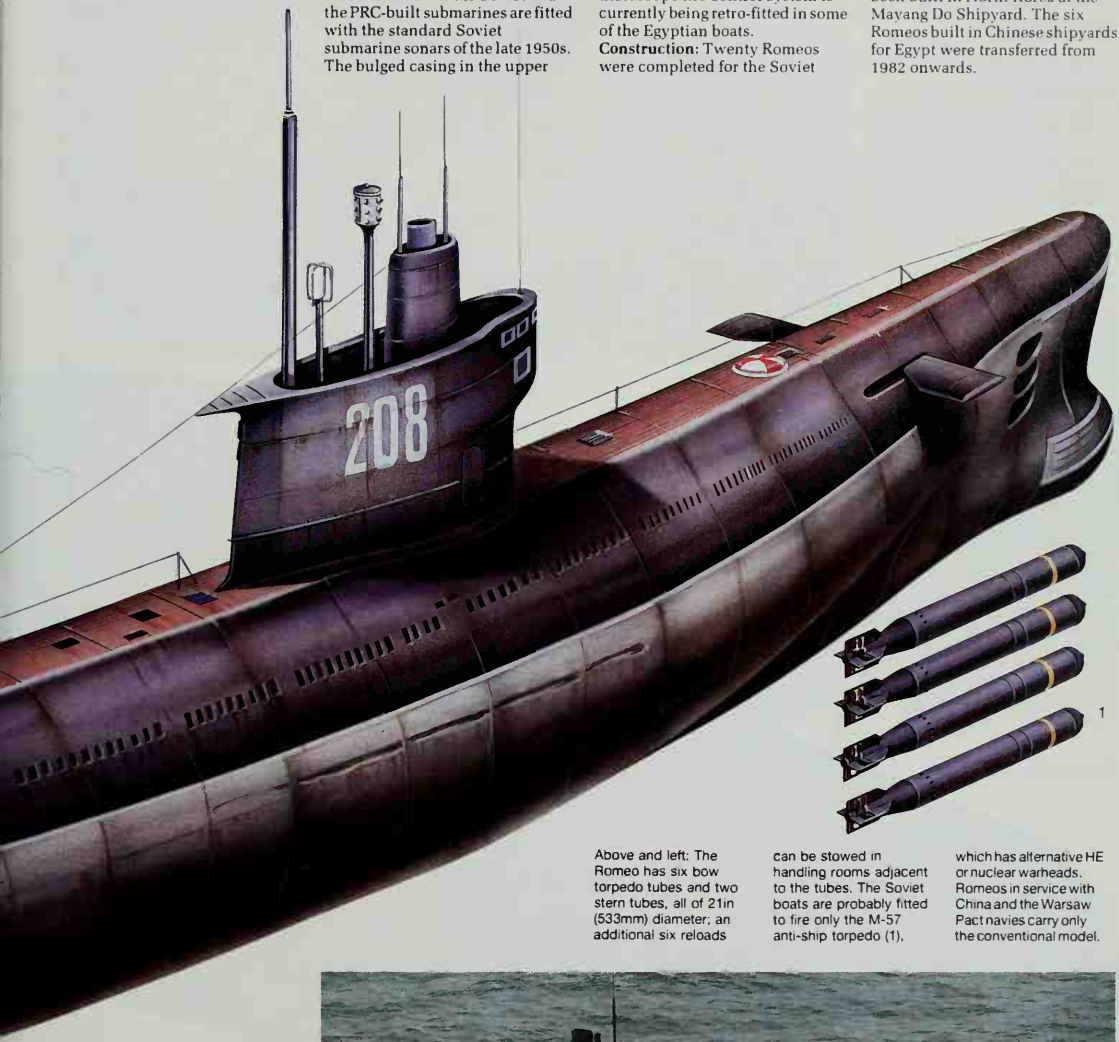


Above: A Romeo of the Soviet Navy photographed on the surface in 1979. The Romeo was originally intended as a successor to the Whiskey, but the construction programme was drastically curtailed as a result of policy changes which occurred in the late 1960s, and only 20 boats were completed.

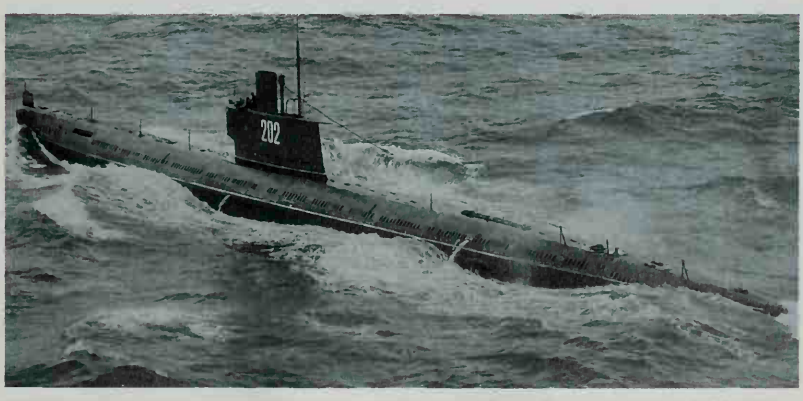
free-running model dating from the 1950s. Some units may also have been updated to fire more recent torpedoes with an ASW capability, and the boats in service with the Soviet Navy will also undoubtedly also carry nuclear-tipped torpedoes (probably two). The Romeos in service with the North Korean and PRC Navies are probably equipped with an anti-surface torpedo derived from the early Soviet models. The Romeos built in China for the Egyptian Navy are apparently being fitted with Western fire control systems which would allow them to fire the more advanced torpedoes currently available for export.

Electronics: Both the Soviet and the PRC-built submarines are fitted with the standard Soviet submarine sonars of the late 1950s. The bulged casing in the upper section of the bow houses a Feniks passive array, and atop the bow there is a Tamir-5L active attack sonar housed in a small dome. Mast-mounted sensors comprise search and attack periscopes, a Snoop Plate surveillance radar, Quad Loop DF, Stop Light ESM, and aerials for HF and VHF communications. A Singer Librascope fire control system is currently being retro-fitted in some of the Egyptian boats.

Construction: Twenty Romeos were completed for the Soviet Navy by the Gorky Shipyard between 1958 and 1962. Eighty-four units were completed for the PRC Navy at the Wuzhang, Guangzhou, Jiangnan and Huludao Shipyards between 1960 and 1982. An additional seven units were built for North Korea and transferred between 1973 and 1975. Ten further boats have since been built in North Korea at the Mayang Do Shipyard. The six Romeos built in Chinese shipyards for Egypt were transferred from 1982 onwards.



Above and left: The Romeo has six bow torpedo tubes and two stern tubes, all of 21in (533mm) diameter; an additional six reloads can be stowed in handling rooms adjacent to the tubes. The Soviet boats are probably fitted to fire only the M-57 anti-ship torpedo (1), which has alternative HE or nuclear warheads. Romeos in service with China and the Warsaw Pact navies carry only the conventional model.

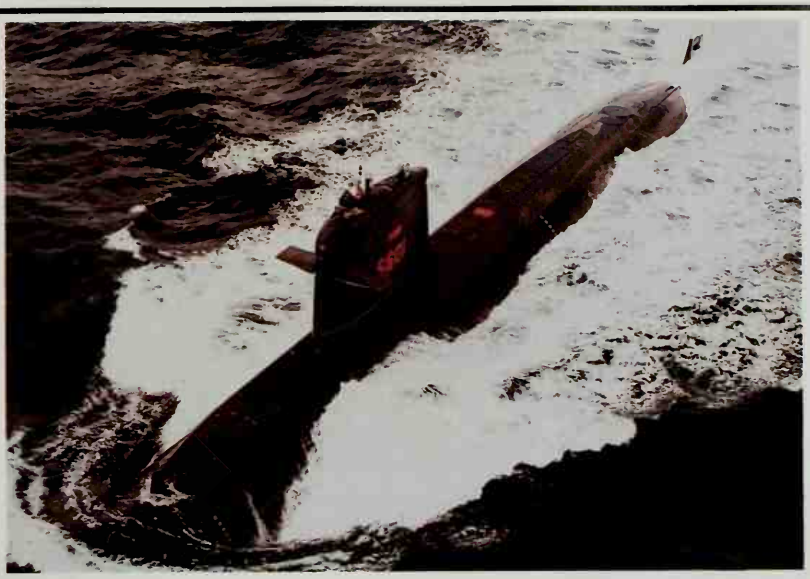


Right: An early view of a Soviet Romeo in the English Channel. Although these medium submarines lost favour with the Soviet Navy because of their relatively short range and because they lacked the necessary size to carry cruise missiles, the design was transferred to the People's Republic of China, which by the early 1980s had completed no fewer than 90 units. Because of the relative simplicity of the design the Romeo has proved popular as an export submarine.

Rubis class

Origin: France, first unit completed 1982
Type: Attack submarine, nuclear-powered (SSN)
Displacement: 2,350 tons surfaced; 2,630 tons submerged
Dimensions: Length 237ft (72.1m); beam 25ft (7.6m); draught 21ft (6.4m)
Propulsion: One 48MW pressurized water-cooled reactor with turbo-electric drive; two turbo-alternators driving one main electric motor; one shaft; 9,500hp for 25kt max
Complement: 66
Background: The first attempt by the Marine Nationale to build a nuclear-powered attack submarine dates from 1954, when the first feasibility studies were begun, and the first hull, number Q-244, was laid down at Cherbourg two years later. However, political friction between France and the United States led the latter country to deny France the enriched uranium needed to fuel the reactor. Development of a heavy water reactor using natural uranium was therefore begun, but this proved to be too large and heavy for submarine installation. The French then attempted to purchase a complete submarine reactor from the United States, but this request was also refused, and led to the abandonment of the project. French interest in SSN construction was re-established with the authorisation of a new type of boat in 1964, but this project was overtaken by the SSBN construction programme, which assumed priority. By the time the Marine Nationale returned again to the SSN project in the early 1970s, its constructors could call upon the valuable experience gained in the course of the SSBN programme. The result was an exceptionally compact design little bigger than the diesel-powered submarines of the Agosta class, and with many common elements with regard to weapons and sensors.
Design: The small size of the Rubis and her sisters is due to the development of a compact, integrated reactor-exchanger which takes up little internal hull volume and has had the effect of minimizing the weight allocated to shielding. Steam from the reactor is superheated before passing through two turbines. Each turbine drives one large and one small alternator. The large alternators generate power for the main electric motor, while the smaller alternators supply power to the auxiliary systems on board. The single shaft has a large-diameter five-bladed propeller. The cooling system uses natural circulation during normal running but is pump-assisted at higher speeds. There is an emergency diesel generator capable of driving the submarine for 50nm in the event of reactor failure. In contrast to the French diesel boats the Rubis has a single hull, which is closed by a hemispherical bulkhead at its after end and by a flat bulkhead pierced by the torpedo tubes at its forward end. This allows for a two-deck layout beneath the fin for the control and accommodation spaces. The pressure hull is constructed of Marel high-tensile steel, which gives the Rubis a diving depth of 985ft (300m), and the adoption of a positive discharge system for the torpedoes enables firing to take place at any depth. The forward hydroplanes, which are fin-mounted, and the cruciform after control surfaces are controlled by autopilot from a one-man console.
Armament: The four bow tubes are 21in (533mm) in diameter and can therefore handle only the most recent models of French torpedo. The L 5 Mod.3 acoustic-homing antisubmarine torpedo is carried, as is the new F 17. The latter is wire-guided and is produced in both anti-ship and antisubmarine (F 17P) versions. The F 17 has a length of 19ft 5in (5.9m), and has a maximum speed of 35 knots and a range of 20,000yds (18,000m). *Saphir*, the second unit of the class, was the first to carry the SM 39 Exocet anti-ship missile, and *Rubis* will be retro-fitted with the necessary fire control equipment in the near future. The SM 39, which is 15ft 5in (4.7m) long and has a diameter of only 14in (350mm), is too small to be fired from a conventional torpedo tube. The missile is therefore encased in a capsule for launch. The SM 39 has a range of 27nm (50km) and employs active radar homing. The small size of the Rubis has resulted in a somewhat reduced torpedo capacity: only 14 torpedoes or missiles can be accommodated, as compared with 20 in the diesel-powered Agosta.
Electronics: The sonar outfit of the

***Rubis* (S 601)**



Rubis class is essentially similar to that of the Agosta class, with an active/passive DUUA 2B attack sonar located in the upper part of the bow, and a DSUV 22 circular hydrophone array below the torpedo tubes. The DUUX 5 Fénelon passive ranging sonar, an advanced model which ran trials aboard the Daphné-class submarine *Doris* from 1977, has been installed in place of the DUUX 2 which equipped earlier boats. DUUG/AUUD sonar intercept gear is fitted, and there are TUUM HF and LF underwater telephones. Torpedo fire control is provided by the now-standard DLT D-3 system, and mast-mounted sensors include search and attack periscopes, a DRUA-33 surveillance radar, and ARUR and ARUD intercept aerials.

Construction: An ambitious construction programme which includes five submarines of the Rubis class plus a further five SSNs of an improved design is proceeding slowly, with only two boats completed to date. The fifth boat is due to enter service in 1990.

Above: *Rubis* is the smallest nuclear-powered submarine ever built. The design was made possible by the development of a particularly compact integrated reactor-exchanger, which has reduced the size and weight of the propulsion machinery. Note the adoption of fin-mounted hydroplanes on the US pattern.

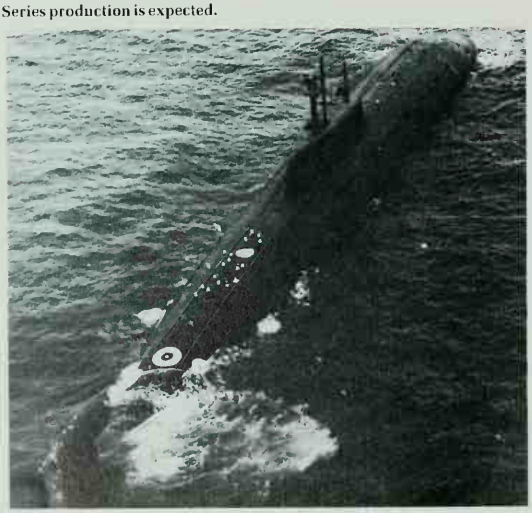
Below: The launch of *Saphir* at Cherbourg in 1981. The bow section housing the forward ballast tank and sonar arrays is yet to be fitted, all submarines of the class being launched with the pressure hull complete up to the flat forward bulkhead. Series production is proceeding slowly, with only two boats completed by early 1987 and three more scheduled for completion by 1990.

Left: The Rubis has four 21in (533mm) bow tubes and can stow 14 reloads. The L 5 acoustic-homing antisubmarine torpedo (1) is carried, as is the new wire-guided F-17 (2). A dual-purpose variant of the latter, the Mod.1, is now entering service. *Saphir* can also fire the SM 39 Exocet anti-ship missile (3), which has a range of 27nm (50km), and two TSM 3510 mines (4) can be carried in place of a single torpedo.

Sierra class

Origin: USSR, first unit completed in 1984
Type: Attack submarine, nuclear-powered (SSN)
Displacement: 6,000 tons surfaced; 7,550 tons submerged
Dimensions: Length 360ft (110m); beam 36ft (11m); draught 25ft (7.5m)
Propulsion: One two pressurized water-cooled reactors driving geared steam turbines; one shaft; 40,000shp for 32kt max
Complement: 85
Design: The Sierra was one of three new Soviet attack submarine types which entered service in 1984-85. The Mike, which has a hull of titanium and may also have a liquid metal-cooled reactor, appears to be a high-technology development of the Alfa (q.v.). The Akula is a conventional steel-hulled boat with a pressurized water-cooled reactor, and in appearance closely resembles the Victor III. The Sierra is similar in overall size and construction to the Akula, thereby posing the question as to why the Soviets should choose to embark on the simultaneous construction of two separate types of SSN with similar capabilities. The Akula and the Sierra appear to be fitted with an identical outfit of sensors, and both are thought to be able to handle the full range of tube-launched missiles and torpedoes in the current Soviet inventory. One theory suggested is they are competing designs produced by different design bureaux, and that the Soviet Navy will embark on series production of either one or the other following extensive trials. However, given that the first Akula was built at the Komosomolsk Shipyard in the Pacific (which also participated in construction of the Victor III) and the first Sierra was built at Gorky in the western USSR, it may be that the designs are not so much 'competing' but regionally based, in the same way that the Kresta II and Kara-class BPKs were 'regional' designs. Only when a pattern of construction has been established will a more accurate assessment be possible.
Design: The Sierra is some 13ft (4m) longer than the Victor III, and has a broader beam. The latter is almost certainly related to measures intended to reduce machinery noise. The increase in beam would make it possible to isolate the propulsion machinery and its associated pumps and gearing from the hull by installing it on an insulated 'raft'. It is not yet clear whether two smaller reactors or a larger single reactor is employed, but a maximum speed in excess of 30 knots can be expected. The single shaft has a seven-bladed propeller which is also a feature of the Akula and the Mike. The fin is broad and squat in comparison to that of the Victor III, and is significantly shorter than that of the Akula. The forward hydroplanes, which are fully retractable, are mounted closer to the bow than was the case with earlier Soviet SSNs. The stern section terminates in the now-standard cruciform tail surfaces, with a teardrop-shaped pod identical to that of the Victor III atop the rudder fin. The lines of square free-flood holes along the outer casing testify to Soviet persistence with double-hull construction.
Armament: Six bow tubes are fitted. These are a mix of standard 21in (533mm) tubes and the new 26in (650mm) tube, although it is not yet clear how many of each there are. Standard anti-ship and acoustic-homing antisubmarine torpedoes can be fired from the 21in (533mm) tubes, which can also launch the SS-N-15 nuclear-tipped antisubmarine missile (see Victor) and the new SS-NX-21 cruise missile. The latter is similar in conception to the US

Below: The Sierra is one of three new types of Soviet SSN. Laid down and launched at Gorky in the western USSR, the first unit was completed and ran trials in the area of the Northern Fleet. Series production is expected.



Right: The Sierra has six bow tubes, with a mix of 21in (533mm) and 26in (650mm) diameters. All submarine weapons in the current inventory can be handled, including the SS-NX-21 land attack missile (1), which carries a nuclear warhead and can be fired from a conventional 21in tube. The 21in tubes can also fire the SS-N-15 nuclear-tipped antisubmarine missile (2) and conventional ASW homing torpedoes (3); mines (4) can be carried instead. The large-diameter tubes can fire the SS-N-16 conventional ASW missile (5) and the Type 65 wake-homing anti-ship torpedo (6).

Navy's Tomahawk. It has an estimated maximum range of 900-1,200nm (1,700-2,250km) and is probably fitted with a nuclear warhead. The current version is for land attack, although subsequent variants may have an anti-ship capability. The 26in (650mm) tubes can launch both the SS-N-16 torpedo-carrying antisubmarine missile and the new Type 65 torpedo, which has a range estimated at 54nm (100km) and homes on the wake of a surface ship.

Electronics: The Sierra has a large active/passive bow sonar, probably a development of the model installed in the Victor. Fire control capabilities will doubtless have been improved to enable the submarine to handle the full range of Soviet tube-launched weapons.

A towed hydrophone array is deployed from the pod-shaped housing atop the tail-fin. Mast-mounted sensors include: search and attack periscopes, the new Snoop Pair/Rim Hat surface surveillance radar/ESM combination, Park Lamp VLF reception, Pert Spring satellite navigation, and Shot Gun VHF communications. Other sensors have not been revealed. Curiously, the Sierra lacks the twin hatches for VLF buoys abaft the fin which are a feature of all other recent Soviet nuclear boats.

Construction: The first unit of the Sierra class was launched at the inland Gorky Shipyard in July 1983, and the incomplete hull was subsequently transferred via the White Sea Canal to Severodvinsk for fitting out. The submarine entered service in late 1984. There is as yet no evidence of series production, but it was expected that additional units of both the Sierra and Akula classes would be launched in 1986.

Right: The Sierra is slightly longer than the Victor III and has a broader, more cylindrical hull-form. Mast-mounted sensors include the distinctive Snoop Pair/Rim Hat surveillance radar/ESM combination. The prominent pod atop the tail-fin is thought to house a towed hydrophone array.

Skipjack class

Origin: USA, first unit completed 1959
Type: Attack submarine, nuclear-powered (SSN)
Displacement: 3,075 tons surfaced; 3,500 tons submerged
Dimensions: Length 252ft (76.7m); beam 31ft 6in (9.6m); draught 28ft (8.5m)
Propulsion: One S5W pressurized water-cooled reactor driving geared steam turbines; one shaft; 15,000shp for 30kt max
Complement: 114
Background: The US Navy's development of the nuclear-powered submarine proceeded rapidly following the completion of the *Nautilus* (SSN 571) in 1954. However, the Americans did not rush immediately into series production, preferring instead to evaluate a number of reactors of different design. At the same time, experiments were continuing with new hull-forms, the revolutionary *Albacore* having commissioned barely a year before *Nautilus*. The first US attempt at a production design, the Skate class, had a relatively small pressurized water-cooled reactor and a conventional hull based on the *Nautilus*. This limited underwater speed to a maximum of 20 knots. For the next class, however, the US Navy decided to combine the newly-developed S5W reactor (which was to become standard in US nuclear boats until the 1970s) with the hull-form of the *Albacore*. The result was a submarine with the exceptionally high underwater speed of 30 knots – a speed unequalled by any other operational submarine in the world until the Soviet Victor class appeared in the late 1960s. The performance of the Skipjacks was such that they continued to be regarded as 'first-line' submarines throughout their service lives.
Design: The Skipjacks were the first US nuclear-powered submarines to have a single hull. This had the effect of reducing overall size while maximizing internal volume. They were also the first nuclear boats to employ a single shaft, the five-bladed propeller being located abaft cruciform control surfaces. This arrangement was to set the standard for later nuclear submarines. It also precluded the installation of stern torpedo tubes, which were a feature of the twin-shaft Skate class. The reactor compartment is 20ft (6.1m) long, and all the other major components of the machinery installation are duplicated to provide redundancy. There are two heat exchangers, two pressurized-water coolers, two sets of turbines and two groups of turbo generators. Two small emergency motors linked to the single shaft and powered either by batteries or by two small diesel generators can bring the submarine home in the event of reactor failure. The Skipjacks have an exceptionally large fin which distinguishes them from later US nuclear boats, and they were the first operational submarines in the world to have their forward hydroplanes mounted on the fin. They were also the first US submarines, together with their diesel-powered contemporaries of the Barbel class, to have a centralised attack centre.
Armament: The Skipjacks have six Mk 59 bow tubes of 21in (533mm) diameter. During the 1960s these could fire a combination of the Mk 14/16 antiship torpedo, the Mk 37 antisubmarine torpedo, and the nuclear-tipped Mk 45 ASTOR. The Mk 14 and its hydrogen peroxide-powered derivative, the Mk 16, were straight-running torpedoes dating from World War II. They were 20ft 6in (6.25m) long, and had a diameter of 21in (533mm). The Mk 37 was developed postwar, and combined electric propulsion with active/passive acoustic homing. The Mod.0 and Mod.3 variants were both free-running, with a length of only 11ft 3in (3.4m), but the Mod.1 and Mod.2 variants were wire-guided, and therefore incorporated an additional section which increased length to 13ft 6in (4.1m); both types had a diameter of 19in (481mm) to enable them to swim out of 21in tubes. Discharge was therefore relatively silent. The small size of these torpedoes enabled two to be carried in place of a single large torpedo in the submarine's reload racks. The Mk 45 ASTOR was also wire-guided because US policy emphasised full control over nuclear weapons at all times. It was unpopular with US submariners because fire control for the torpedo implied active sonar operations which tended to

Right: The Skipjacks are fitted with six Mk 59 bow tubes of 21in (533mm) diameter. As completed these submarines were armed with three distinct types of torpedo; the Mk 14/16 anti-ship torpedo, the short Mk 37 ASW homing torpedo, and the MK 45 ASTOR, a large antisubmarine torpedo with a nuclear warhead. All three types have now been replaced by the Mk 48 (1), a fast-running heavyweight torpedo with optional wire guidance which can be used against both surface ships and submarines. Lacking the sophisticated fire control sonars of later US Navy attack submarines, the Skipjacks were never fitted to fire the SUBROC missile, and their advanced age has precluded the installation of more modern systems.

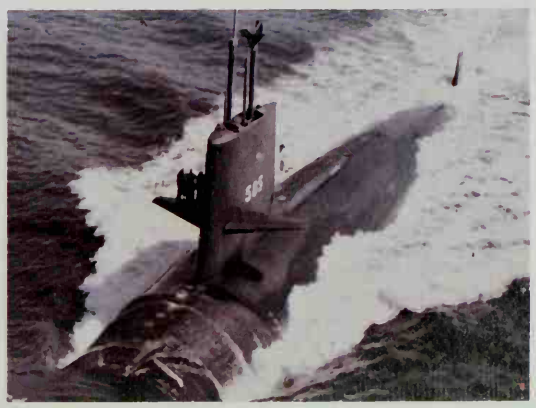
USS *Skipjack* (SSN 585)

give away the position of the submarine, and the weapon was duly discarded in the early 1970s. As production of the dual-purpose Mk 48 torpedo increased in the late 1970s, the Mk 14 and Mk 37 torpedoes were also progressively replaced.

Electronics: The Skipjacks have a modified BQS-4 active/passive sonar which transmits through a circular BQR-2C passive array. The BQS-4 can operate in the 'single-ping' or listening modes and has a maximum range of 6-8,000 yds (5,500-7,200m). The BQR-2 is a listening array which can operate in the searchlight or scanning mode and has a range of 10-13,000yds (9,000-11,700m). Mast-mounted sensors include search and attack periscopes, a BPS-12 surface surveillance radar, communications aerials, and direction-finding and ESM antennas. The original analogue Mk 113 fire control system has been replaced by the digital Mk 117, but no further updates are planned.

Construction: Six submarines of the Skipjack class were completed between 1959 and 1961 at four different shipyards. Of these Scorpion (SSN 589) was lost in May 1968, approximatly 400 miles southwest of the Azores, and Snook (SSN 592) was deactivated in 1986.

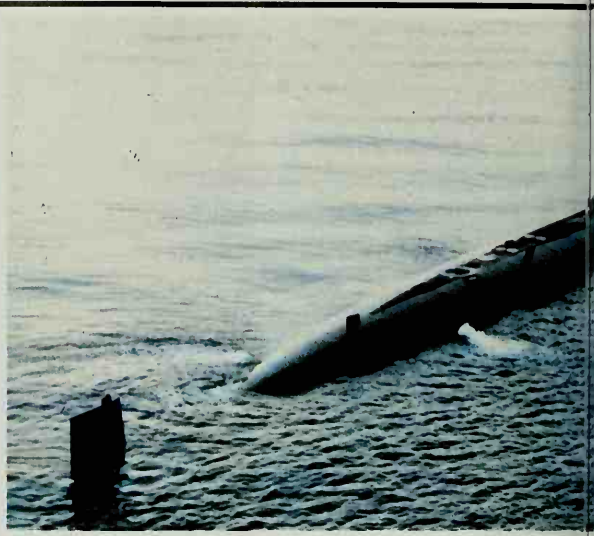
Above: The Skipjacks were the first US Navy attack submarines to combine the 15,000shp S5W pressurized water-cooled reactor with the revolutionary 'Albacore' hull-form. Underwater speed exceeded 30 knots, and the performance of these submarines was such that they remained in first-line service for over 25 years until they began to decommission in the mid-1980s.



Right: A bow view of *Scamp* (SSN 588); note the continuous curve of the hull-form and the prominent hydroplanes mounted on the fin. The high underwater speed of these boats was not to be equalled until *Los Angeles* commissioned in late 1976.

Sturgeon class

Origin: USA, first unit completed 1967
Type: Attack submarine, nuclear-powered (SSN)
Displacement: 4,250/4,460 tons surfaced (see remarks); 4,780/4,960 tons submerged
Dimensions: Length 292ft/302ft (89m/92.1m); beam 31ft 8in (9.7m); draught 29ft (8.8m)
Propulsion: One S5W pressurized water-cooled reactor driving geared steam turbines; one shaft; 15,000shp for 26kt max
Complement: 107
Background: The Sturgeons were the natural successors to the Thresher/Permit class boats. The latter suffered from a number of design compromises which were accepted in order to minimize underwater speed loss. These included a small fin with inadequate numbers of mast-mounted antennas, and limited electronics. The Sturgeon design was therefore enlarged to provide the necessary internal volume for more effective quieting and additional electronics, producing a boat which was to become the standard attack submarine of the period. However, the US Navy continued to produce experimental designs to investigate further improvements in submarine propulsion: the *Narwhal* (SSN 671, in service 1969) tested a natural circulation reactor, the S5G, which was to appear in an enlarged form in the SSBNs of the Ohio class (qv), and the *Glenard P Lipscomb* (SSN 685, in service 1974), tested a natural circulation reactor with turbo-electric drive. Both these submarines are operated as first-line units, and have similar larger submarines all powered by the same S5W reactor has resulted in some speed loss, and it was in part to restore this quality that the Los Angeles class was developed in the early 1970s.



Below: *Richard B. Russell* (SSN 687), the last unit of the class to be completed. The later boats were 10ft (3m) longer to facilitate the installation of the BQQ-5 sonar suite, but the steady progression to

Right: The Sturgeons are fitted with four 21in (533mm) torpedo tubes angled out beneath the fin and carry a similar mix of weapons to that of the Permit class. The normal weapon load is reported to be 15 Mk 48 dual-purpose torpedoes (1), four SUBROC antisubmarine missiles (2), and four Sub-Harpoon anti-ship missiles (3). Some units are being fitted to fire the long-range Tomahawk missile.

Above: *Richard B. Russell* modified with a housing for a prototype communications buoy abaft the fin. No fewer than 37 Sturgeons were completed between 1967 and 1975, making them the standard US SSN of the period. The design was a modified version of the Permit class, with a larger fin to accommodate additional electronics.

weapons outfits and electronics to the Sturgeons.

Design: The Sturgeon class follows the general arrangement of the Thresher/Permit class, with the bow occupied by the BQS-6 spherical array and the torpedo tubes angled out beneath the fin. An enlarged control room/attack centre, which extends aft from beneath the fin, accommodates additional computerised fire control consoles, enabling the Sturgeons to engage multiple targets. The machinery spaces were also lengthened for more effective noise insulation. The major external difference between the Sturgeon and the Thresher/Permit class is the substantially enlarged fin, which accommodates additional sensor masts for ESM. The fin-mounted hydroplanes are 38ft (11.6m) wide and can be rotated to the vertical to enable the submarines to break through ice packs. The last nine units of the class were lengthened by 10ft (3m) to facilitate the installation of the BQQ-5 sonar suite and its associated electronics, and as earlier units are retro-fitted with the new system they too are being lengthened.

Armament: Like the Thresher/Permit class, the Sturgeons are equipped with four 21in (533mm) Mk 63 torpedo tubes which are angled out beneath the fin. As first completed they carried a similar mix of anti-ship and antisubmarine torpedoes, plus the SUBROC missile. SUBROC (UUM-44A-2) entered operational service in 1965. It comprises a two-stage solid-fuel rocket with a ballistic trajectory and a nuclear warhead. A maximum range of 25-30nm (45-55km) is reported. SUBROC was to have been discarded as US Navy SSNs had their analogue Mk 113 fire control systems replaced by the digital Mk 117, but because of the absence of a natural replacement in the short term, Congress stipulated that the SUBROC fire control system be modified so that the missile could be kept in service. From 1972 the earlier models of torpedo were steadily replaced by the dual-purpose Mk 48. The latter is a high-performance torpedo using a liquid mono-propellant for propulsion to achieve a maximum speed of 55 knots. It is 19ft 6in (5.95m) long and has a maximum range of 40-45,000yds (35-40,000m). The Mk 48 was specifically designed to engage deep-diving submarines, and has a maximum operating depth of 2,500ft (760m). From the late 1970s Sturgeon-class boats began to receive the Sub-Harpoon anti-ship missile. Harpoon was designed primarily for surface-ship operation and is too small to be accommodated in a standard torpedo tubes; it is therefore launched inside a capsule from which it separates on breaking the surface. The missile itself is 15ft (4.6m) long and has a maximum range of 70-85nm (130-155km). At present submarines of this class are reported to carry 15 Mk 48 torpedoes, four SUBROC missiles and four Sub-Harpoon missiles. Some units of the class are currently being equipped to fire the long-range Tomahawk missile (see Los Angeles).

Electronics: As completed the Sturgeons received the BQQ-2 sonar suite, comprising the BQS-6 active/passive spherical bow array, the BQR-7 conformal passive array, and a PUFFS fire control sonar. The BQQ-2 installation is currently being upgraded to BQQ-5 status, and the BQR-23 towed array is being fitted. Mast-mounted sensors include search and attack periscopes, a BPS-14 or BPS-15 surveillance radar, UHF communications, and no fewer than four masts carrying DF and ESM antennae. There are also whip and floating wire aerials for communications, and in 1978 two units received an afterward extension to the fin for a towed communications array.

Construction: Thirty-seven submarines of the Sturgeon class were completed between 1967 and 1975 in six different shipyards.

Sturgeon class
Richard B. Russell (SSN 687)

Swiftsure class

Origin: United Kingdom, first unit completed 1973
Type: Attack submarine, nuclear-powered (SSN)
Displacement: 4,200 tons surfaced; 4,900 tons submerged
Dimensions: Length 272ft (82.9m); beam 32ft 4in (9.8m); draught 27ft (8.2m)
Propulsion: One PWR 1 pressurized water-cooled reactor driving geared steam turbines; one shaft; 15,000shp for 30kt max
Complement: 97
Background: The Swiftsures were designed as the natural successors to the SSNs of the Valiant class. The weapon/sensor suite was little changed, and in the early units of the class was virtually identical to that of their immediate predecessors. However, the opportunity was taken for a complete hull redesign, and major modifications were made to the propulsion machinery in order to take into account experience gained with the Valiants and incorporate the latest quieting measures. This had the effect of reducing overall length by 13ft (4m) and the submerged displacement by 400 tons.
Design: In the Swiftsure and her sisters the cylindrical portion of the pressure-hull was extended as far aft as possible to eliminate structural transitions which had led to stress problems in the Valiants. The 'Albacore' hull of the earlier design has therefore been superseded by a broadly cylindrical hull-form with an exceptionally broad tail-cone. The shape of the forward half of the boat remains relatively unchanged, although here too the pressure hull has been broadened to accommodate a completely different layout of the torpedo tubes and torpedo handling room. As with the US Navy Permit/Thresher class, the height of the fin was significantly reduced in order to lower resistance. This led in turn to a reduction in periscope depth. As compensation the forward hydroplanes were lowered and made fully retractable. The torpedo handling room was relocated below the two main decks directly beneath the fin. Two of the five torpedo tubes are angled out on either side of the boat immediately abaft the chin sonar, in the manner of contemporary US Navy SSNs, and the fifth is presumably angled downwards on the centre-line and fires through the underside of the bow. This arrangement frees the bow for the sonar installation. The other major modifications concern the propulsion plant, which differs considerably in conception and layout from that of the Valiants. In the latter design the raft on which the main turbines and gearing were mounted had to be locked in when running at high speed. In the Swiftsures not only the turbines and gearing but virtually all noise-emitting auxiliary machinery is mounted on the raft, obviating the need for flexible couplings. The raft can therefore be isolated from the hull even at maximum power. As a further quieting measure, natural circulation was adopted for the reactor. Circular water scoops are located in the leading edges of the horizontal tail-fins, and these provide sufficient cooling through most of the power range, the coolant pumps being employed only at higher speeds. The improvements in quieting are such that the Swiftsures have dispensed with the separate main electric motor which was a feature of the Valiant propulsion plant. This has created a more compact layout in the machinery spaces and made it possible to reduce the overall length of the pressure hull. A small retractable motor, driven by a 112-cell battery charged by a 400bhp Paxman auxiliary diesel, is retained to provide power in an emergency.
Armament: The five bow torpedo tubes are of the standard 21in (533mm) calibre. An estimated 15 reloads are carried in the handling room. All units of the class were fitted to fire the Mk 24 Tigerfish antisubmarine torpedo from the outset. Tigerfish entered service in 1974, but numerous problems

Below: *Splendid*, the fifth boat of the Swiftsure class. The design has proved particularly successful, and the Trafalgar class currently in production is essentially evolutionary.

Right: The Swiftsures have five 21in (533mm) torpedo tubes, and an estimated 15 reloads can be accommodated. All six boats now carry the Mk 24 Tigerfish Mod.1 torpedo (2), which has a dual-purpose capability. A Mod.2 variant with improved guidance is undergoing trials. The class is also being retro-fitted to fire the Sub-Harpoon anti-ship missile (2). Two Stonefish (3) or Sea Urchin (4) mines can be carried in place of one torpedo.

were encountered both in development and after the weapon was deployed, and work on improved models has continued into the mid-1980s. The dual-purpose Mod.1 variant entered service around 1981 and has replaced the elderly Mk 8 anti-ship torpedo, and a Mod.2 variant with improved guidance has recently undergone trials. Tigerfish has a length of 21ft 2in (6.4m) and has a sophisticated two-way wire guidance system with automatic three-dimensional active/passive homing. It has a maximum range of 12,000yds (11,000m) at a speed of 40 knots. In addition to torpedoes, all units of the class will be refitted to fire Sub-Harpoon in the late 1980s.

Electronics: As completed the Swiftsures had a sonar outfit virtually identical to that of the Valiant: a Type 2001 active/passive 'chin' array, a Type 2007 passive flank array, and a Type 197 intercept array. Later boats of the class were fitted with the Type 2019 Passive Active Range and Intercept Sonar (PARIS), a joint Anglo-Dutch-French development. The Type 2019 is now being retro-fitted to earlier boats. Fire control is provided by a DCB Action Information and Fire Control System. The Type 2026 towed array is currently being fitted, and it is envisaged that all units of the class will have their Type 2001 bow array replaced by Type 2020, beginning with *Superb* in 1985.

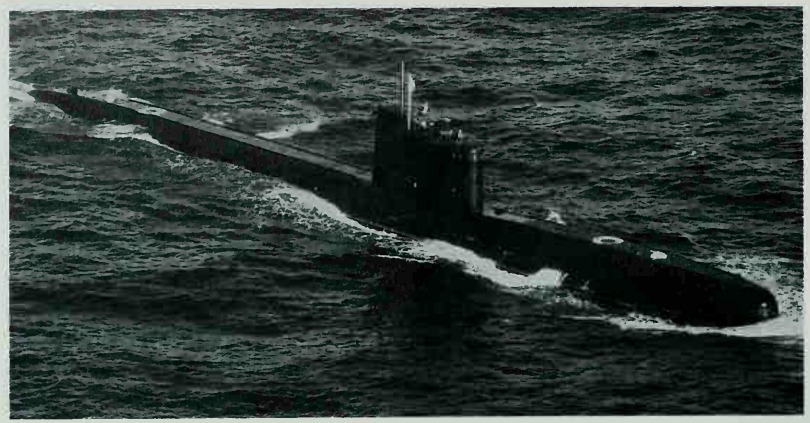
Construction: Six submarines of the Swiftsure class were completed at the Vickers Shipyard, Barrow-in-Furness, between 1973 and 1980.

Above: A bow view of HMS *Superb*. In this class the cylindrical portion of the pressure-hull was extended as far aft as possible to eliminate stress problems which had been experienced with the Valiant class. The forward hydroplanes are mounted low on the forward section of the hull and are fully retractable, permitting a reduction in the height of the fin.

Tango class

Origin: USSR, first unit completed 1972
Type: Attack submarine, diesel-powered (SS)
Displacement: 3,200 tons surfaced; 3,900 tons submerged
Dimensions: Length 302ft (92m); beam 30ft (9m); draught 23ft (7m)
Propulsion: Diesel-electric drive on two shafts; three diesel generators, two electric motors; 6,000bhp for 15kt surfaced, 5,500hp for 16kt submerged
Complement: 72
Background: The large Foxtrot programme was completed in 1968, by which time the concept of the large ocean-going submarine with a primary scouting/torpedo attack mission had dated. The attention of the Soviet Navy, which until the early 1960s had been focused almost exclusively on the anti-surface mission, now turned towards antisubmarine warfare. The nuclear-powered Victor (qv) was the first Soviet submarine type to be designed for the ASW mission. However, the initial production rate was necessarily slow because of the greater priority accorded to the construction of SSBNs of the Yankee and Delta classes, which in the early 1970s were being built at the rate of five or six per year. Until the late 1970s, when the SSBN programme began to tail off, construction of the Victor was limited to a single shipyard, and the Soviet Navy therefore adopted its customary solution of designing a diesel-powered counterpart, which became the Tango. The new submarine would have similar weapons and sensors to the Victor, and great emphasis was placed on endurance, to enable the Tango to undertake lengthy patrols in defence of the Soviet 'bastion' areas.

Design: In profile the Tango closely resembles the earlier Foxtrot, but first appearances are deceptive. Whereas the Foxtrot has a traditional cigar-shaped hull-form based on the German Type XXI, the Tango has a hull-form which is essentially cylindrical, and while length remains virtually unchanged, these boats have 5ft (1.5m) more beam than the Foxtrot. Moreover, the cylindrical hull configuration is maintained throughout the length of the boats, whereas the hull-form of the Foxtrot is tapered towards the bow and stern. The improved hull-form has a broader, more modern hull-form than its predecessor. The raised bow section is thought to be related to the provision of additional stowage space for the SS-N-15 antisubmarine missile and its associated fire control electronics.



Above: The Tango succeeded the Foxtrot in production in 1972. Although the two types are not dissimilar in profile, the Tango

is responsible for a substantial increase in internal volume, especially in the fully-rounded bow section, where the large low-frequency bow sonar is located. Greater space was also required in order to accommodate the SS-N-15 antisubmarine missile, together with the necessary fire control consoles, and battery capacity has been substantially increased over earlier Soviet diesel boats to give improved underwater endurance. The result is a submarine of 50% greater displacement than the Foxtrot. There is some disagreement regarding both propulsion machinery and the position and number of the torpedo tubes. US sources generally favour an arrangement similar to that of the Foxtrot, with one diesel and one motor on each of three shafts, and four stern tubes. However, other Western sources appear to favour a two-shaft installation with three diesel generators and two electric motors, with all torpedo tubes in the bow. This arrangement would conform more closely to that of the Victor, and therefore seems more logical given that the missions and weapon systems of the two types are virtually identical.

Considerable emphasis has been placed on silencing, and the Tango is particularly quiet when operating on its electric motors: long slotted free-flood apertures have been adopted in preference to the more numerous limber holes of the Foxtrot, most of the deck fittings are recessed, and the hull has been sheathed in a sonar-absorbent rubber compound.

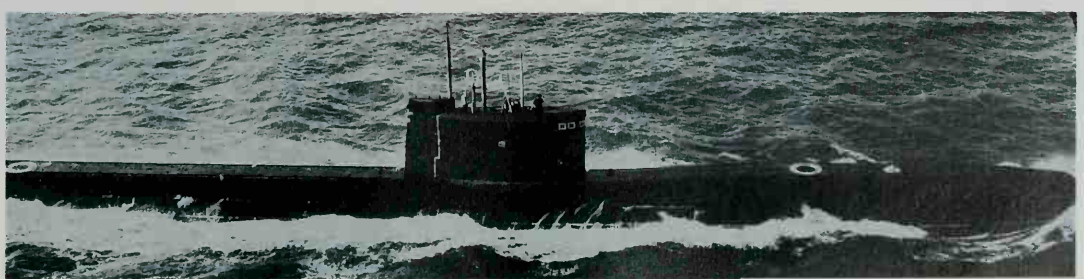
Armament: The six (possibly eight) bow tubes are all of the standard 21in (533mm) diameter. They can fire conventional or nuclear-tipped anti-ship torpedoes, antisubmarine torpedoes with acoustic homing, and the SS-N-15 nuclear-tipped antisubmarine missile. There is a relatively large stowage capacity for perhaps 16-18 missiles and torpedoes. There is as yet no evidence to suggest that the large-diameter 26in (650mm) tube will be retro-fitted although, given the primary ASW mission of the Tango, this must be considered a possibility for the future once the nuclear boats (which are presumably being given priority) have been modified.

Sensors: The Tango has a large low-frequency active/passive bow sonar - probably the same model installed in the Victor - and presumably has fixed conformal passive arrays along the hull. The outfit of sensor masts is standard, but there are minor variations between the early and later boats of the class. All have search and attack periscopes, a Snoop Tray surface surveillance radar, Quad Loop DF, and aerials for HF and VHF communications. Early boats have Stop Light ESM, but later units have a variant of the more modern Brick Pulp antenna which is a feature of Soviet nuclear-powered submarines of the Victor generation.

Construction: Nineteen Tangos were completed between 1972 and 1982 at the inland Gorky Shipyard, but production has apparently been terminated in favour of the Kilo.

Below: The Tango has six (possibly eight) bow tubes each of 21in (533mm) diameter. The new large-diameter 26in (650mm) tube is not fitted, nor are there stern tubes as in the earlier Foxtrot class, and the weapons carried are thought to be identical to those of the early Victors, which have a similar mission. There are long 21in torpedoes (1) for use against surface ships; some of these will be fitted with a nuclear warhead. There will also be shorter 21in antisubmarine homing torpedoes employing acoustic guidance (2). The third major weapon is the SS-N-15 missile (3), which can be used against both submarines and surface targets; the SS-N-15 has a nuclear warhead and a range of about 22nm (40km). In addition to the six weapons carried in the tubes, the Tango has sufficient stowage space for an estimated 18 reloads. In place of each missile or torpedo two mines (4) could be carried.

Below: Nineteen Tangos were built between 1972 and 1982 at the inland Gorky Shipyard, but production of the class has now been discontinued in favour of the Kilo. The Tango is one of the largest diesel-electric submarines ever built, and has sufficient endurance to undertake lengthy patrols in defence of the Soviet SSBN 'bastions' in the Northern and Pacific Fleet areas.



TR-1700

Origin: Export design by Thyssen (FRG), first unit completed 1984
Type: Attack submarine, diesel-powered (SS)
Displacement: 2,115 tons surfaced; 2,265 tons submerged
Dimensions: Length 216ft 6in (66m); beam 24ft (7.3m); draught 21ft 4in (6.5m)
Propulsion: Diesel-electric drive on one shaft; four MTU 16V652 MB80 diesel generators, each 1,475bhp; one Siemens electric motor; 5,900bhp for 13kt surfaced, 8,970hp for 25kt submerged
Complement: 29
Background: Until the mid-1970s the Thyssen (formerly Rheinstahl) Nordseewerke Shipyard, Emden, had built submarines to IKL designs. Fifteen Type 207 (Kobben class) submarines were completed for Norway between 1964 and 1967, and orders were subsequently received for ten of the fifteen Type 206 boats for the Federal German Navy, the last being completed in 1975. In September 1973 the upper limit on displacement permitted to German shipyards by Treaty was raised to 1,800 tons standard, and Thyssen took full advantage of this development to design a high-performance ocean-going submarine which would appeal to Third World countries anxious to replace their elderly ex-US Navy 'Guppies' with modern construction. Unlike IKL's successful Type 209, which was essentially an enlargement of the Type 205/206 coastal submarines built for the German Navy, the TR-1700 was designed from the keel up. The hull and propulsion machinery are German, but the best in foreign technology has also been incorporated. The equipment is flexible to suit customer preferences, and the design itself has been developed both upwards (the TR-1700A) and downwards (the TR-1400 and TR-1000). However, the only order which has so far materialised is for Argentina, which ordered four TR-1700s in 1977. The first pair was to be built in Germany and the second pair under licence. An order for two smaller TR-1400s, also for Argentina, was cancelled in favour of two further locally-built TR-1700s in 1982.
Design: The Type 1700 employs single-hull construction. The 158ft (48m) pressure hull, which is of uniform diameter throughout except for a short tapered section aft, is of high-tensile steel, for a diving depth of 1,000ft (300m). It is closed by a hemispherical bulkhead forward and a flat bulkhead aft, and is divided into three sections, separated by two further transverse bulkheads. The forward section is on three levels, with the officer accommodation above the torpedo stowage compartment and the forward batteries beneath. The midships section has the central control room above the accommodation for the crew, with internal tanks below. A lock-out chamber in the fin allows for diver operations with the submarine submerged. The after section, which occupies more than half the length of the submarine, houses the exceptionally powerful propulsion machinery and the auxiliary machinery. The switchboard room is in the forward compartment, followed by a long central compartment which houses the four MTU diesel generators on the upper level with the after battery bank beneath. The third compartment is occupied by the large Siemens double-armature

Above: ***Santa Cruz*****, the first of the TR-1700s to be completed for the Argentinian Navy. A second German-built boat was delivered in 1985, and three further units are currently under construction in a specially designed shipyard in Buenos Aires.**

TR-1700 ***Santa Cruz*** **(Argentinian S 33)**

electric motor, which can produce 8,000hp sustained, and 8,970hp for short periods. This gives the TR-1700 the remarkable maximum underwater speed of 25 knots. Power is provided by no fewer than eight 120-cell banks of Varta batteries. The adoption of extensive automation has made possible a complement of only 29 men, which is exceptionally small for a boat which approaches the size of the British Upholder and the Dutch Walrus class. The SAGEM diving controls are operated from a one-man console. In a departure from the IKL designs, the forward hydroplanes are mounted on the fin, and are complemented by cruciform tail surfaces.

Armament: There are six torpedo tubes of standard 21in (533mm) diameter, disposed in two banks of three. The capacious stowage room can accommodate 16 reloads. The Argentine Navy currently has in service the German SST-4 wire-guided anti-ship torpedo and the US Mk 37C short antisubmarine torpedo. Severe budgetary constraints make it unlikely that more modern torpedoes will be purchased in the short term, although the TR-1700 has been designed to fire a wide range of internationally-available types.

Electronics: An integrated active attack and passive search/intercept/ranging sonar suite has been installed in the Argentine boats. The precise identity of this equipment has not been revealed, but it seems probable that it is a development of the Krupp-Atlas CSU 3-4 multi-function array fitted in other recent German export submarines. The HSA SINBADS Action Information Organisation and Fire Control system is combined with a SAGEM plotting table. Mast-mounted sensors include Kollmorgen search and attack periscopes, surveillance radar and passive ESM.

Construction: The first two units for Argentina were completed at the Nordseewerke, Emden, in 1984-85. However, progress on the four locally-built units has been slow, and the precarious financial situation has led to rumours that the boats may be sold 'off the slipway'. The first was laid down only in late 1983, and work on the third was begun in 1985.

Above: One of the Argentinian TR-1700s under construction at the Norseewerke Shipyard, Emden. Unlike other German export submarine designs, the TR-1700 was designed from the keel up as an ocean-going boat with good long-range endurance. A maximum underwater speed of 25 knots can be sustained for short periods. Note the large propeller under canvas.

Opposite: The TR-1700 has six bow torpedo tubes of 21in (533mm) diameter. The torpedoes currently in service with the Argentinian Navy are the heavyweight SST-4 (bottom), which is an export development of the Seeal wire-guided heavyweight anti-ship torpedo, and the US Mk 37C short antisubmarine torpedo (top), which also employs wire guidance. It is not yet clear whether the Argentinian Navy will attempt to purchase the more recent SUT (Surface/Underwater Target) torpedo.

Trafalgar class

Origin: United Kingdom, first unit completed 1983
Type: Attack submarine, nuclear-powered (SSN)
Displacement: 4,800 tons surfaced; 5,300 tons submerged
Dimensions: Length 280ft (85.4m); beam 33ft (10.1m); draught 27ft (8.2m)
Propulsion: One PWR 1 pressurized water-cooled reactor driving geared steam turbines; pump-jet (see remarks); 15,000shp for 28-30kt max
Complement: 98
Background: The Swiftsure class proved particularly successful in service. The following design, the Trafalgar, therefore kept to the same basic hull-form and layout. However, some six years had elapsed between the two designs, and during that interval several major advances had been made in electronics and acoustic detection methods. The Trafalgar was to incorporate the latest quieting measures, and would be fitted with a new generation of underwater sensors.
Design: The Trafalgar is some 8ft (2.5m) longer than the Swiftsure, and submerged displacement has increased by 800 tons, suggesting that a significant quantity of additional equipment has been worked into the design. The hull-form and internal layout of the two submarines is virtually identical, but a number of detail improvements have been incorporated. The major modifications relate to the propulsion plant, the reactor featuring a new core (Core Z) with a longer life than earlier types. All main propulsion and auxiliary machinery, including the turbines, reduction gearing, pumps and condensers, is raft-mounted as in the Swiftsure. In the Trafalgar class, however, the raft is suspended from transverse bulkheads, not mounted on the hull, in order to provide more effective insulation. Natural circulation via water scoops located in the leading edges of the horizontal tail-fins has been retained, and the reactor coolant pumps are required only at higher speeds. However, in place of the conventional seven-bladed propeller of the Swiftsures, the Trafalgars employ a shrouded pump-jet. Pump-jets, which have already been used to propel torpedoes such as the US Navy's Mk 48, comprise a single multi-blade rotor turning relatively slowly against stator vanes in a duct. In effect the pump-jet is a high-pitch, low-revolution propeller. Pump-jets are significantly quieter than conventional propellers, but the installation brings with it a considerable cost in weight. This can be sustained in the Trafalgars largely because of the unusual 45-degree tail-cone angle, which provides additional buoyancy at the after end of the submarine. It is reported that the US Navy's new Seawolf (SSN-21) design will also have pump-jet propulsion. Development of the British pump-jet was not completed in time for installation aboard *Trafalgar* herself, which has similar shaft arrangements to the Swiftsures, and the second unit of the class, *Turbulent*, is believed to be the first Royal Navy submarine to be fitted with the system. A further innovation on the Trafalgar class is the adoption of anechoic hull tiles in order to reduce acoustic signature.
Armament: The Trafalgars have identical torpedo firing and handling arrangements to the Swiftsures, with five tubes of 21in (533mm) diameter firing through the sides and underside of the hull immediately abaft the bow sonar. Trafalgar was fitted from the outset to fire the Mod.1 dual-purpose variant of the Mk 24 Tigerfish torpedo, which entered service around 1981. This gave her a completely homogeneous torpedo outfit and enabled her to dispense with the elderly Mk 8 anti-ship torpedo. All Tigerfish torpedoes will shortly be brought up to the Mod.2 standard, which has improved guidance. The Trafalgars also carry the Sub-Harpoon missile, for which they have been fitted since completion. A further potential weapon is the Stonefish mine, specifically developed by Marconi Underwater Systems for deployment from a 21in (533mm) torpedo tube. Stonefish is an intelligent, programmable mine which uses the latest microprocessor technology for target assessment. It is of modular design, and can be allied to either a 660lb (300kg) or a 1,320lb (600kg) warhead according to the anticipated water depth.
Electronics: The Trafalgars are the first Royal Navy submarines to be

Below: *Turbulent*, the second unit of the Trafalgar class, is thought to be the first submarine to be fitted with a pump-jet instead of a conventional propeller.

Right: The Trafalgars are fitted with five 21in (533mm) torpedo tubes located just abaft the bow, and are armed with the Mk 24 Tigerfish torpedo (1), which now has a dual-purpose capability. They were also fitted from the outset to receive the Sub-Harpoon anti-ship missile (2), which is encapsulated for launch from a torpedo tube. Mines of various types can be carried, including the Stonefish (3), and Sea Urchin (4) programmable mines developed by Marconi Underwater Systems.

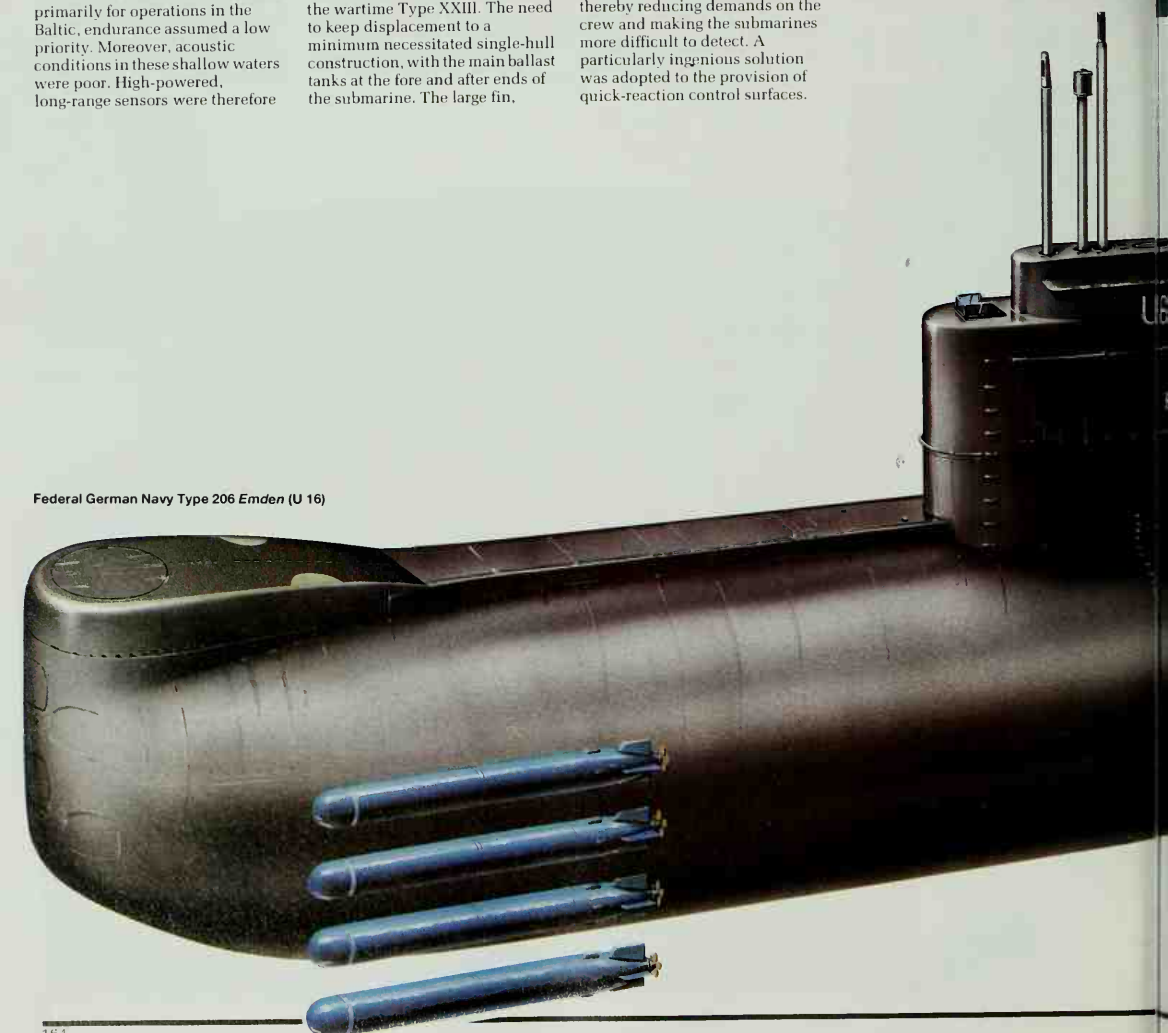
fitted with the advanced Type 2020 sonar on completion. The Type 2020 is a passive low-frequency array developed from the Type 2016 surface ship sonar installed in frigates of the Broadsword class. It is scanned electronically and gives full 360-degree coverage. The Type 2020 is now replacing the Type 2001 'chin' array in earlier Royal Navy SSNs. Besides Type 2020 the Trafalgars are fitted with a Type 2007 passive flank array, a Type 2019 sonar intercept array and the Type 2026 towed array. The latter has brought with it remarkable improvements in long-range detection and tracking capabilities. A DCB Action Information Organisation and Fire Control system is fitted.

Construction: Four submarines of the Trafalgar have been completed since 1983. Three further boats are under construction, but there will then have to be a pause in SSN construction for the Royal Navy to enable the new Vanguard-class Trident submarines to be built.

Above: *Trafalgar*, the name-ship of the class, is essentially a refined Swiftsure, from which she is virtually indistinguishable externally. Improvements include a new long-life reactor core, anechoic hull-tiling and a new generation of sensors. The Type 2020 sonar occupies the bow of the submarine, as in US Navy attack boats, and the torpedo tubes are angled out abaft the bow. The retractable sonar dome forward of the fin is for a Type 2019 sonar intercept array.

Type 206

Origin: Federal Republic of Germany, first unit completed 1971
Type: Coastal submarine, diesel-powered (SSC)
Displacement: 456 tons surfaced; 500 tons submerged
Dimensions: Length 159ft 6in (48.6m); beam 15ft (4.6m); 14ft (4.3m)
Propulsion: Diesel-electric drive on one shaft; two MTU 12V493AZ diesels, each 600hp; one Siemens electric motor; 1,200bhp for 10kt surfaced, 2,300hp for 17.5kt submerged
Complement: 21
Background: In the immediate postwar period Germany was forbidden to build submarines. Subsequently, an upper limit of 350 tons was placed on submarine construction, and only conventional diesel-electric propulsion was permitted. These constraints taxed to the full the ingenuity of the German designers, who were compelled to rethink submarine design concepts *ab initio*. As the new submarines were primarily for operations in the Baltic, endurance assumed a low priority. Moreover, acoustic conditions in these shallow waters were poor. High-powered, long-range sensors were therefore of limited value. What was needed was a small, agile submarine capable of operating comfortably at snorkel depth for long periods, and with a powerful battery of torpedo tubes to cope with the multiple targets which might be expected in the event of an attempted amphibious landing by the forces of the Warsaw Pact. The earliest attack submarine design, the Type 201, quickly ran into problems when it was found that the anti-magnetic steel employed in the construction of the first three boats was subject to serious corrosion. The last nine boats of the class were therefore rebuilt as the Type 205. In 1962 the upper limit for tonnage was raised to 450 tons, and the German Navy embarked on the design of an improved class, the Type 206, which would take into account experience with the earlier boats and which would incorporate improvements in sensors and weapons.
Design: The hull design of Types 201, 205 and 206 is based on that of the wartime Type XXIII. The need to keep displacement to a minimum necessitated single-hull construction, with the main ballast tanks at the fore and after ends of the submarine. The large fin, which has a prominent conning tower at its forward end, is in part a concession to the need for surface transit in peacetime, but was also needed in order to accommodate a full outfit of retractable sensor masts. The bow is of near-circular cross-section, making possible an outfit of no fewer than eight bow tubes of the large-diameter, 'swim-out' type. This launch method saves weight, as positive discharge methods impose greater space and power requirements. Muzzle-loading is employed, so that the space normally required for torpedo handling and stowage is given over to the accommodation of the crew. In the forward half of the boat there is a single-deck layout, with the control room directly abaft the crew spaces and the battery compartments beneath. The silver zinc battery cell developed by Hagen/Varta for these submarines has twice the capacity of other battery cells of the period and a very fast reload cycle. This results in shorter snorkelling periods, thereby reducing demands on the crew and making the submarines more difficult to detect. A particularly ingenious solution was adopted to the provision of quick-reaction control surfaces. The forward hydroplanes are curved and fully retractable, and are used alternately, one to produce a bow-up and the other a bow-down angle. The after planes are integrated with the stabilisation fin. The rudder is abaft the single propeller.
Armament: The eight bow tubes are of 26in (660mm) diameter, but fire 21in (533mm) torpedoes. Early German postwar torpedoes were of the free-running type, but the Type 206 was designed to fire a new generation of wire-guided torpedoes. Seeal, a heavy-weight anti-ship torpedo, was 21ft (6.4m) long and had a range of 7nm (13km) at 35kt; Seeschlange, an antisubmarine torpedo based on the US Mk 37, had a length of 13ft 1in (4m) and a range half that of Seeal. Both torpedoes employed electrical propulsion and two-way wire guidance, but in the antisubmarine variant a 3-D sonar



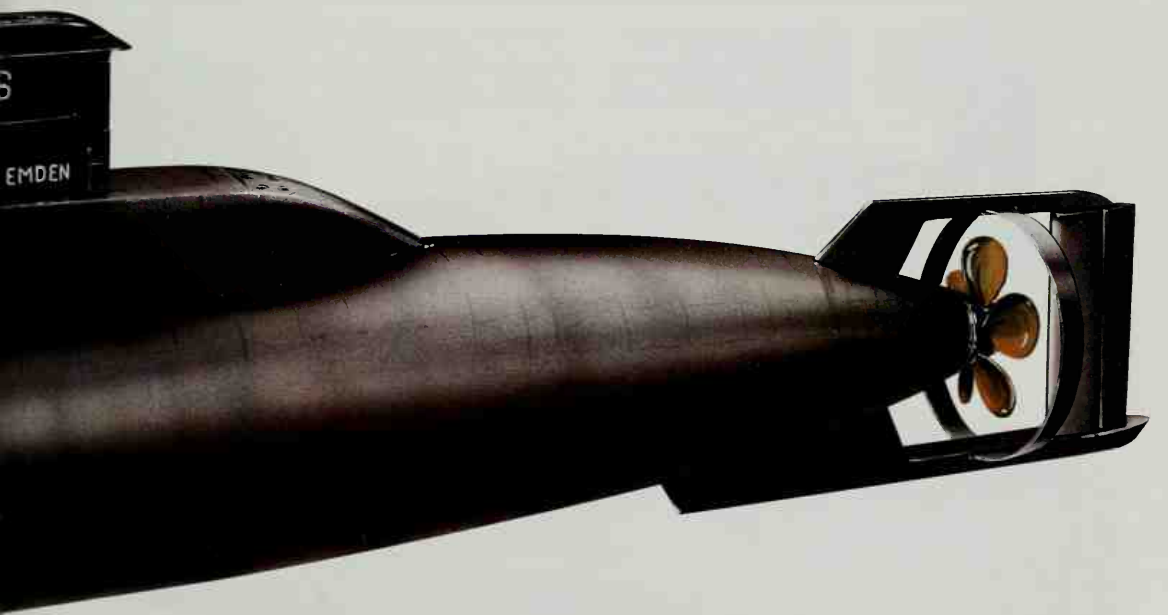
Federal German Navy Type 206 *Emden* (U 16)

Above: U 29, the last but one of the 18 units built for the Federal German Navy. The Type 206 is an ingenious design which has turned postwar Treaty constraints to its advantage, and the class has not only proved successful in service with the FRG, but has also provided the basis for the Type 209 design which has dominated the export markets for the past 15 years.

replaced half the battery capacity. Seeal and Seeschlange have now been superseded by the SUT (Surface/Underwater Target) heavyweight torpedo, which has a length of 22ft (6.7m) and can be fired against both surface ships and submarines. In addition to torpedoes, these submarines can carry 24 mines in GRP containers strapped around the hull.

Sensors: The Type 206 has a comprehensive sonar outfit comprising an AN 5039A1 passive array, an AN 410A4 active ranging sonar, and a French DUUX 2 fire control sonar. An HSA Mk 8 Action Information Organisation and Fire Control System is fitted. Twelve out of the 18 units of the class are to undergo an extensive modernisation, beginning in 1989, during which a Krupp-Atlas CSU 83 (NATO designation: DBQS-21) integrated sonar system will replace the original sonar outfit, and the HSA Mk 8 combat system will be superseded by the SLW 83.

Construction: Eighteen units of the Type 206 class were completed between 1971 and 1974, construction being shared between Howaldtswerke, Kiel, and Rheinstahl-Nordseewerke, Emden.



Opposite: The submarines of the Type 206 class have no fewer than eight bow tubes of the large-diameter, 'swim-out' type. Initially the submarines carried a mix of Seeal heavyweight anti-ship torpedoes and Seeschlange 'short' antisubmarine torpedoes, both of which employed wire guidance. These have now been superseded by the SUT (Surface/Underwater Target) heavyweight torpedo shown, which can be used against both surface ships and submarines. Because of their small size the submarines of the Type 206 class have no space for reloads. However, a belt comprising glass-reinforced plastic mine containers has been specially developed for the type. The mine belt has a capacity of 24 mines.

Type 209

Origin: Export design by IKL (FRG), first unit completed 1971
Type: Attack submarine, diesel-powered (SS)
Displacement: Type 209/0: 1,105 tons surfaced, 1,230 tons submerged
Type 209/1: 1,180 tons surfaced, 1,290 tons submerged Type 209/2: 1,260 tons surfaced, 1,390 tons submerged
Type 209/3: 1,320 tons surfaced, 1,440 tons submerged
Dimensions: Type 209/0: length 178ft 6in (54.4m)
Type 209/1: length 184ft (56.1m)
Type 209/2: length 195ft 3in (59.5m)
Type 209/3: length 200ft (61m)
All variants: beam 20ft 4in (6.2m); draught 18ft (5.5m)
Propulsiun: Diesel-electric drive on one shaft; four MTU 12V493 TY60 diesel generators, each 600bhp; one Siemens electric motor; 2,400bhp for 11kt surfaced, 5,000hp for 22kt (max) submerged
Complement: 30-33
Background: The completion of the Type 201/205 submarine programme for the Federal German Navy in the late 1960s coincided with the completion of 15 similar Type 207 (Kobben class) boats for Norway. The German shipyards, which had built up their design and construction capacity to a relatively high level, were faced by a prospective shortage of orders, and were compelled to turn to the export market. Treaty restrictions continued to limit (standard) displacement to a maximum of 1,000 tons. The designers Ingenieurkontor Lübeck (IKL), working in conjunction with the Howaldtswerke-Deutsche Werft shipyard, therefore proposed an enlarged version of the Type 205 coastal submarine which would incorporate the technologies developed for the German Navy's own submarine programme. The design proved particularly attractive to Third World countries with limited budgets, and the Type 209 has been ordered by no fewer than 12 navies, with construction both in Germany and under licence.
Design: The Type 209 has many features in common with the submarines of the Type 205 and Type 206 classes in service with the Federal German Navy. These include single-hull construction, eight 'swim-out' torpedo tubes disposed in a broadly circular arrangement, single-shaft propulsion with a five-bladed propeller, and retractable fixed-angle bow hydroplanes. However, full advantage has been taken of the increase in displacement to provide an enlarged fin, stowage capacity for torpedo reloads, and more powerful propulsion machinery.

Above: The Type 209 is the most successful export design of the postwar period. No fewer than 31 units – including the Colombian *Islay* shown here – have been ordered from the HDW Shipyard in the Federal Republic of Germany, and a further ten are being built under licence with German technical assistance.

Right: The Type 209 has eight swim-out tubes capable of firing any torpedo of 21in (533mm) diameter. Most of the navies which have purchased the Type 209 employ two complementary types of torpedo: generally the 'long' SST-4 anti-ship torpedo shown here and the short NT-37C antisubmarine torpedo, which is of US origin. The German SUT dual-purpose torpedo is reported to be in service with the navies of Chile, Colombia, Ecuador amd Indonesia. Peru has recently ordered the Italian A.184, and Brazil apparently intends to purchase the British Mk 24 Tigerfish.

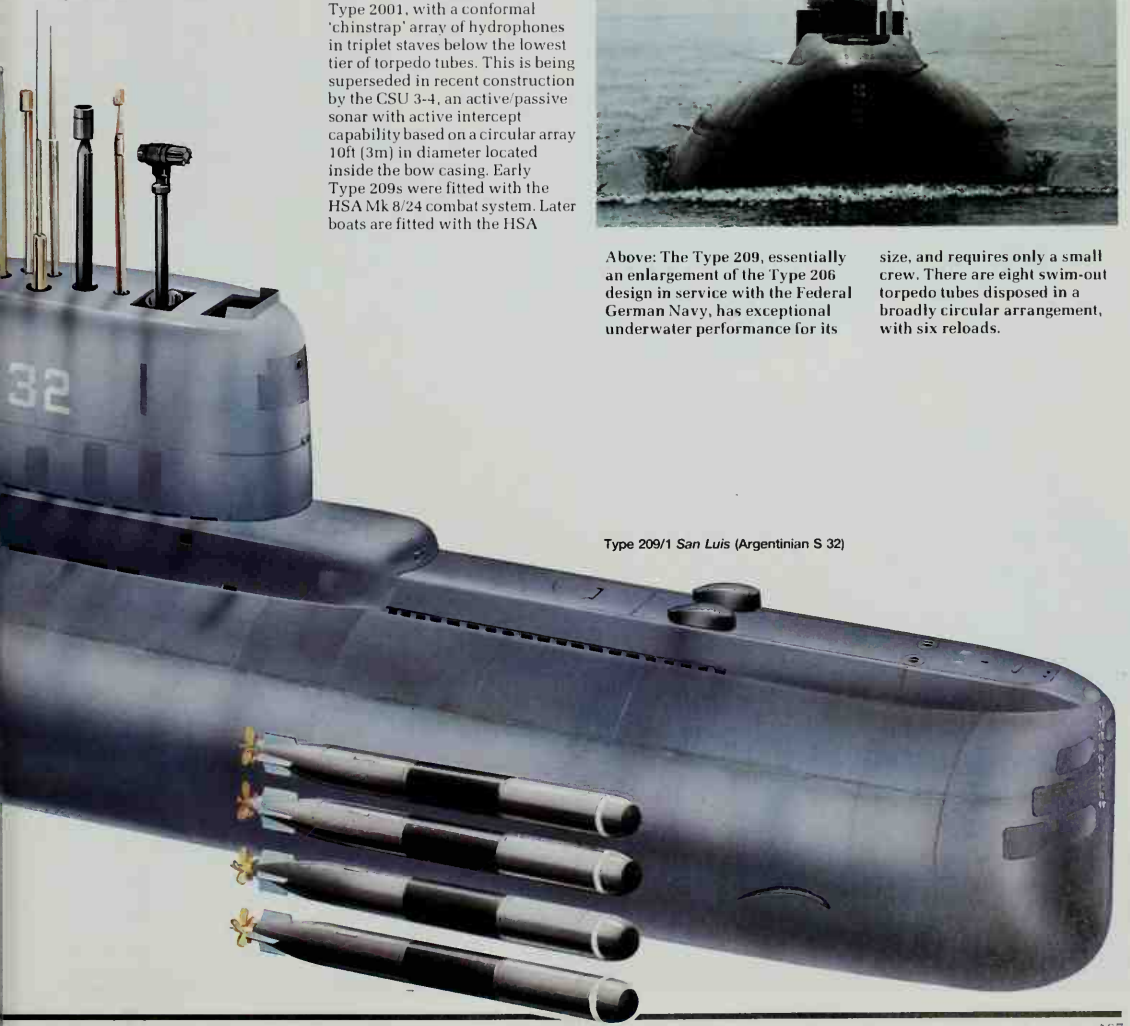
Power for the generators is provided by four MTU diesels, and the double-armature Siemens electric motor, which is resiliently mounted, has more than twice the output of the model installed in the Type 205/206. The Hagen/VARTA batteries are of tubular construction with GRP cell walls, and have 20% higher specific capacity than conventional plate cells, plus high resistance to underwater shock. The batteries have a 4-5 year life expectancy, and take up 25% of internal space. They give the submarines considerable underwater endurance and a maximum speed of 22-23 knots for short periods. The machinery is controlled from a fully-automated control room abaft the attack centre, the engine room itself being completely unmanned.

Armament: The Type 209 has eight 'swim-out' bow tubes capable of firing any torpedo of 21in (533mm) diameter. Six reloads can be accommodated in a stowage rack abaft the tubes. A number of the operating countries have purchased the German SST-4 (Special Surface Target) torpedo, which is the export version of the wire-guided Seeal anti-ship torpedo. The SST-4 is reported to be in service with the navies of Argentina, Greece, Peru, Turkey and Venezuela. In the Peruvian and Argentinian Navies it is paired with the US NT-37C short antisubmarine torpedo. Other countries have purchased the more recent German SUT (Surface/Underwater Target) heavyweight torpedo, which can be fired against both surface ships and submarines. The SUT is thought to be in service with the navies of Chile, Colombia, Ecuador and Indonesia. Peru has recently ordered the Italian A.184 for its Type 209s, and it is reported that the Brazilian boats will be equipped to fire the British Mk 24 Tigerfish Mod.1.

Electronics: Most Type 209s have the Krupp Atlas CSU 3-2 active sonar combined with a PRS 3-4 passive array. The latter is similar in conception to the British Type 2001, with a conformal 'chinstrap' array of hydrophones in triplet staves below the lowest tier of torpedo tubes. This is being superseded in recent construction by the CSU 3-4, an active/passive sonar with active intercept capability based on a circular array 10ft (3m) in diameter located inside the bow casing. Early Type 209s were fitted with the HSA Mk 8/24 combat system. Later boats are fitted with the HSA SINBADS combat system, and the Ferranti (UK) KAFS system is reported to have been selected for the new Brazilian boats.

Construction: Four Type 209/0s were completed for Greece in 1971-72, followed by four Type 209/1s in 1979-81. Two Type 209/1s were completed for Argentina in 1974, two for Colombia in 1975, and six for Peru in 1975-83. Three Type 209/1s were built by IKL for Turkey, and a further three have since been completed under licence at the Gölcük Naval Shipyard, with four more on order. Two Type 209/2s were completed for Venezuela in 1976-77, two for Ecuador in 1977-78, and two for Indonesia in 1981. Two Type 209/3s were completed for Chile in 1984, and five further boats of this type are being built for Brazil.

Above: The Type 209, essentially an enlargement of the Type 206 design in service with the Federal German Navy, has exceptional underwater performance for its size, and requires only a small crew. There are eight swim-out torpedo tubes disposed in a broadly circular arrangement, with six reloads.

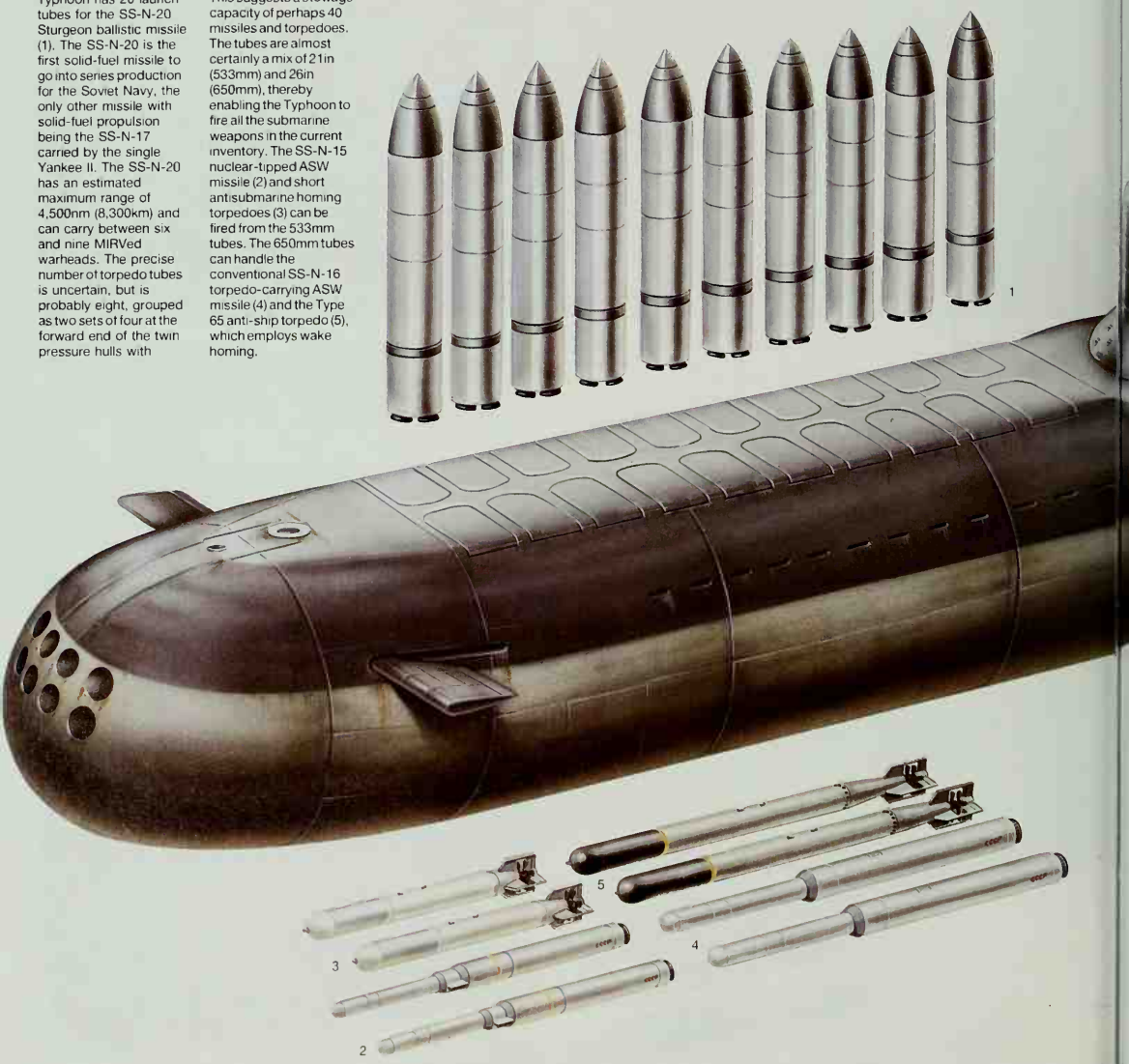


Type 209/1 *San Luis* (Argentinian S 32)

Typhoon

Origin: USSR, first unit completed late 1981
Type: Ballistic missile submarine, nuclear-powered (SSBN)
Displacement: 25-30,000 tons submerged
Dimensions: Length 558ft (170m); beam 75ft (23m); draught 37ft (11.5m)
Propulsion: Two pressurized water-cooled reactors driving geared steam turbines; two shafts; 75-80,000shp for 24kt max
Complement: 150
Background: The original Yankee design on which the Soviet Delta-class SSBNs were based dated from the early 1960s. The nature of Soviet SSBN operations had changed considerably over that period due to the development of long-range SLBMs capable of targeting the territory of the United States from the security of Soviet-controlled waters. This placed a different set of requirements on SSBN design. High performance, which was previously regarded as essential because of the need to transit the NATO antisubmarine barrier in the Greenland/Iceland/United Kingdom (GIUK) Gap, now assumed less importance than endurance and firepower, for which a capacious hull was required. Because the submarines would be operating in relatively friendly waters, fewer hulls each with greater missile capacity were favoured. This fundamental change in operational philosophy has reportedly been accompanied by the introduction of a two-crew manning policy similar to the 'Blue/Gold' arrangement which is employed for all Western ballistic missile submarines.
Design: The Typhoon is a formidable submarine of a completely new design. Novel features include a multiple-hull configuration and the location of the missile compartment forward of the fin. The hull configuration apparently comprises two parallel pressure cylinders about 425ft (130m) long enveloped by a broad outer casing. This results in an exceptionally broad beam of some 75ft (23m), approximately twice that of the Delta. An estimated 6ft (2m) stand-off between the inner and outer hulls is thought to provide some protection against small Western antisubmarine torpedoes launched by surface ships or helicopters. A third, shorter pressure cylinder some 20ft (6m) in diameter is located directly beneath the fin, and houses the attack centre and command spaces. This arrangement is necessary to enable the periscopes and other sensor masts to be located on the centre-line in the conventional way. Each of the large twin pressure cylinders contains its own propulsion unit, comprising a single nuclear reactor and steam turbines driving a seven-bladed propeller. The two propulsion units are almost certainly capable of independent operation, and each presumably has its own machinery control centre and electrical switchboard. This would

Below and right: The Typhoon has 20 launch tubes for the SS-N-20 Sturgeon ballistic missile (1). The SS-N-20 is the first solid-fuel missile to go into series production for the Soviet Navy, the only other missile with solid-fuel propulsion being the SS-N-17 carried by the single Yankee II. The SS-N-20 has an estimated maximum range of 4,500nm (8,300km) and can carry between six and nine MIRVed warheads. The precise number of torpedo tubes is uncertain, but is probably eight, grouped as two sets of four at the forward end of the twin pressure hulls with stowage spaces behind. This suggests a stowage capacity of perhaps 40 missiles and torpedoes. The tubes are almost certainly a mix of 21in (533mm) and 26in (650mm), thereby enabling the Typhoon to fire all the submarine weapons in the current inventory. The SS-N-15 nuclear-tipped ASW missile (2) and short antisubmarine homing torpedoes (3) can be fired from the 533mm tubes. The 650mm tubes can handle the conventional SS-N-16 torpedo-carrying ASW missile (4) and the Type 65 anti-ship torpedo (5), which employs wake homing.

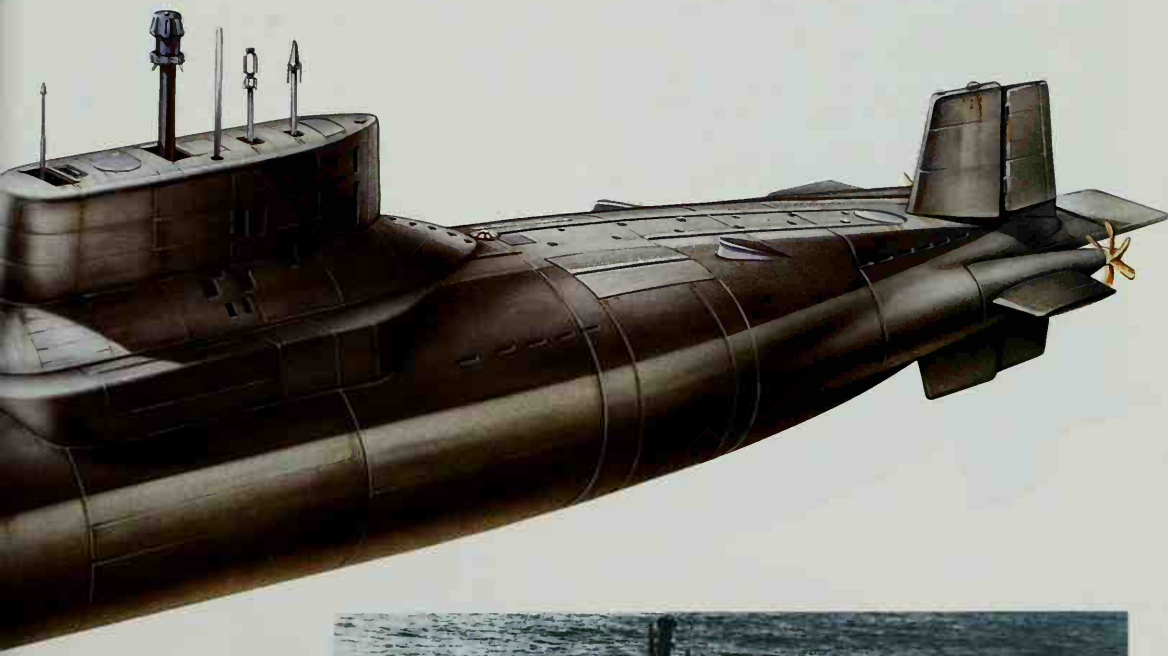


enable the submarine to continue operations even if a complete propulsion unit had to be closed down as a result of failure or action damage. The configuration of the fin and the sturdy tailfin/rudder assembly suggest that the submarine is designed for under-ice operations. The forward hydroplanes are located close to the bow, not on the fin as in earlier Soviet SSBNs. This maximizes control in the vertical plane. The hydroplanes are retractable as in Soviet attack boats, thereby reducing the risk of damage while travelling on the surface in ice-bound waters.

Armament: The Typhoon carries 20 SS-N-20 missiles in a large compartment forward of the fin. The unconventional position of the missile compartment may relate to the concentration of machinery weight in the short after section of the boat. The SS-N-20, a solid-fuel missile with an estimated length of around 50ft (15m) and a diameter of 7ft (2.2m), carries six to nine MIRVed warheads and has a maximum range of 4,500nm (8,300km). The missile could be launched from the Barents Sea or from beneath the Arctic ice pack. Little is known about the torpedo arrangements in the Typhoon. The twin-hull layout suggests four torpedo tubes in each hull with separate handling rooms. Some of these tubes may be of the larger 26in (650mm) diameter to enable the new Type 65 wake-homing torpedo or the SS-N-16 torpedo-carrying derivative of the SS-N-15 antisubmarine missile to be fired.

Electronics: The main active/passive transducer is probably located in the chin of the submarine, and there will undoubtedly be conformal passive arrays along the hull for detection and fire control. Large hatches located side by side abaft the fin house buoys for VLF communications. An extensive array of masts include search and attack periscopes, the distinctive Snoop Pair/Rim Hat surface surveillance/ESM combination, Park Lamp VLF/LF reception, Pert Spring satellite navigation, and Shot Gun VHF communications. There are also numerous unidentified electro-optical sensors.

Construction: The first unit of the class was laid down at the Severodvinsk Shipyard, appropriatly the world's largest submarine production yard, in 1977; she was subsequently launched in August 1980 and began trials in June 1981. The second boat was launched in October 1982 and began trials in June 1983. A third boat entered service in 1985, and a fourth in 1986. The large size of these boats suggests that only the Severodvinsk 402 Shipyard, which has extensive undercover construction halls, will be capable of undertaking their construction. It is therefore considered unlikely that production of Typhoon-class submarines will exceed the rate of one hull every two years.



Right: The Typhoon is the largest submarine ever built. Her length is virtually the same as that of the Delta IV and the US Navy's *Ohio*, but she has almost twice the beam of the latter vessels due to her unusual hull construction, which comprises two long pressure cylinders side by side within a broad outer casing. A third, shorter pressure cylinder housing the command spaces is located within the hump at the base of the fin. The twin pairs of hatches in the after casing house VLF communications buoys.

Upholder class

Origin: United Kingdom, first unit to complete 1988
Type: Attack submarine, diesel-powered (SS)
Displacement: 2,215 tons surfaced; 2,365 tons submerged
Dimensions: Length 230ft 6in (70.25m); beam 25ft (7.6m); draught 21ft 4in (6.5m)
Propulsion: Diesel-electric drive on one shaft; two Paxman Valenta 1600 RPA 200SZ diesel generators, each 2,035bhp; one GEC electric motor; 4,070bhp for 12kt surfaced, 5,400hp for 20kt submerged
Complement: 44
Background: Following the completion of the Oberon programme in 1967 no further submarines with diesel-electric propulsion were contemplated by the Royal Navy. However, with the decision to build Trident submarines it became clear that there would have to be a gap of about eight years in the SSN building programme, because Vickers (Barrow) was the only remaining shipyard with sufficient nuclear construction expertise, and building capacity was limited. Moreover, the Oberons, by this time nearing the end of their service lives, had shown their value in routine patrol operations, and had proved to be inherently quieter than their nuclear counterparts. The Royal Navy therefore opted for a new diesel-electric design, employing as much of the technology developed for the SSN programme as it was possible to incorporate.
Design: The hull-form, which has an exceptionally high beam to length ratio, is closely modelled on that of the British nuclear boats. Single-hull construction has been adopted, and the cylindrical pressure hull is of NQ 1 (HY80-equivalent) steel for a maximum diving depth of 650ft (200m); the fin will be largely constructed of GRP. The large diameter of the pressure hull allows for a spacious two-deck layout. The control room, communications office and ESM office are grouped together beneath the fin, with the weapons stowage forward. The lower deck houses the accommodation and messing spaces, and there are two banks of Chloride lead-acid batteries beneath, each containing 240 cells. The propulsion and auxiliary machinery is located in a single-deck compartment abaft the accommodation decks. In the forward part of the machinery space are the two Paxman 16-cylinder diesel generators, which are mounted on a raft above the fuel tanks. The generator room is separated from the motor room by a transverse acoustic bulkhead. The GEC main motor comprises two motors in a common frame with two armatures on a common shaft. This arrangement makes possible series or parallel combinations, giving a continuous speed range between four and 20 knots. There is a separate motor generator for speeds below four knots. The Upholders have exceptionally high submerged speed, and their large battery capacity gives them an underwater endurance 45 per cent greater than that of the Oberon. They are also capable of sustaining 19 knots while snorkeling. Advanced automation, which includes an autopilot, has made it possible to reduce the complement to only 44 officers and men.
Armament: The six bow tubes are of the standard 21in (533mm) diameter and are disposed in two banks (two in the upper and four in the lower bank) in the upper section of the bow. Positive discharge is used to enable the torpedoes to be fired from any depth. Additional stowage, with hydraulic handling, is provided for a further 12 weapons. Initially the Mk 24 Tigerfish torpedo will be carried, but in the late 1980s this will be superseded by the heavyweight Marconi Spearfish which is currently under development. Spearfish, a high-performance torpedo designed specifically to counter the latest high-speed, deep-diving Soviet SSNs, has a length of 27ft 10in (8.5m), and weighs 4,400lb (2,000kg). Spearfish incorporates a Sundstrand turbine engine, and is reported to have achieved more than 70 knots on trials. Range will be in the region of 70,000 yards

Left: *Upholder*, the first diesel-electric submarine to be built for the Royal Navy for more than 20 years, is modeled on the latest nuclear-powered fleet submarines but costs less than half as much. Seen here at her launch at the Barrow-in-Furness Shipyard of Vickers, *Upholder* is due to enter service in 1988. Three further units have been ordered from Cammell Laird, and it is thought that the class will eventually total ten submarines.

(65,000m). Other weapons carried by the Upholder class will include the Sub-Harpoon anti-ship missile and Stonefish mines.

Electronics: The main active/passive sonar, designated Type 2040, was developed from the French Thomson-CSF Elédone. The passive array, comprising a triple-tier 48-stave circular transducer, is located in the chin of the submarine, while the active ('attack') component is housed inside the forward edge of the fin. Twelve targets can be tracked simultaneously. The Type 2040 will be complemented by the standard Type 2007 passive hydrophone flank array, the Type 2019 passive intercept sonar, and the Type 2026 towed array. The DCC Action Information Organisation and fire control system, developed from the DCA/DCB systems in service aboard Royal Navy SSNs, is based on two FM1600E computers with a digital data bus linked to three dual-purpose consoles. Up to 35 targets can be tracked, and automatic guidance can be provided for four torpedoes against four separate targets.

Construction: The name-ship of the class was laid down at the Vickers Shipyard, Barrow-in-Furness, in November 1983 and is due to enter service in 1988. Three further units were ordered from Cammell Laird in January 1986. The class may eventually total 10 submarines, and it is reported that the fifth boat may be of a 'stretched' 3,000-ton design which will be capable of longer endurance.

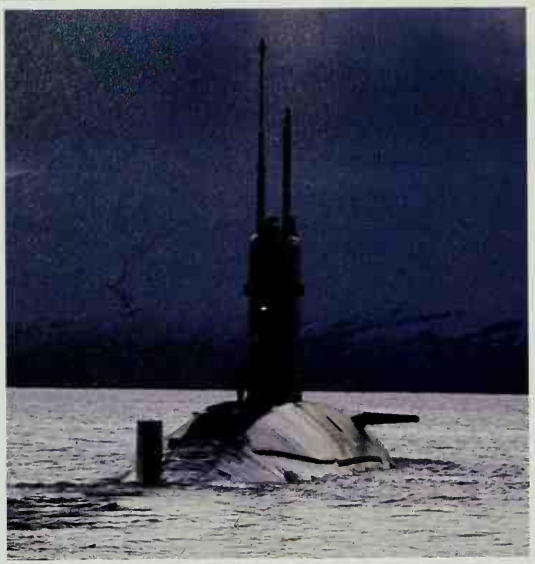
Right: The Upholder class boats have single pressure hulls, cruciform tail surfaces and single seven-bladed propellers. The main ballast tanks are fore and aft of the pressure hull, as in contemporary SSNs. Internally there is a multi-deck layout with a large modern control room, and the latest sensors will be fitted, including a Type 2026 towed array and the Type 2040 bow array, under wraps in this photo of the launching ceremony.

Below: The Upholders will be capable of firing the full range of weapons carried by the latest Royal Navy nuclear-powered hunter-killer submarines and will have six bow tubes of 21in (533mm) diameter. Initially the Mk 24 Tigerfish Mod.2 (1) torpedo will be carried, but this will eventually be superseded by the Spearfish torpedo (2) currently being developed by Marconi. Both types can be used against either surface ships or submarines, but Spearfish will be faster and will have a more sophisticated homing system. The Upholders will also be fitted with the necessary fire control electronics to handle the Sub-Harpoon anti-ship missile (3), which is launched from a canister designed to fit a standard 21in torpedo tube. In place of each torpedo or missile, two Marconi Stonefish mines (4) can be accommodated in the stowage racks. A total of 18 full-size weapons can be carried.

HMS *Upholder* (S 40)

Valiant class

Origin: United Kingdom, first unit completed 1966
Type: Attack submarine, nuclear-powered (SSN)
Displacement: 4,200 tons standard; 4,900 tons full load
Dimensions: Length 285ft (86.9m); beam 33ft 3in (10.1m); draught 27ft (8.2m)
Propulsion: One PWR 1 pressurized water-cooled reactor driving geared steam turbines; one shaft; 15,000shp for 28kt max
Complement: 103
Background: The first British nuclear-powered submarine, HMS *Dreadnought*, was completed in 1963. Because of delays in the British military reactor programme, she was built around an American S5W reactor, which was purchased direct from Westinghouse. The US reactor section was grafted onto a forward section of British design, and British equipment and propulsion machinery were employed. A completely new generation of underwater sensors and combat systems were designed for *Dreadnought*, and these were to be incorporated in later British SSN designs. Meanwhile work proceeded on an all-British reactor at the Admiralty Reactor Test Establishment at Donnreay. This was to be incorporated in a modified design which became the Valiant class. The British SSNs, unlike their US Navy counterparts, are designed to operate in close support of a task force or a convoy, and are designated Fleet Submarines by the Royal Navy.
Design: *Valiant* was slightly larger than *Dreadnought* in order to accommodate the new British PWR 1 reactor, which was bulkier than the American S5W. Single-hull construction was again employed, but the 'Albacore' hull-form was smoother, less disjointed than that of Dreadnought. High-yield UKE



Above: The Valiants were the first nuclear submarines of exclusively British design, *Dreadnought* having been completed with an S5W reactor purchased directly from the United States. They are designated 'Fleet Submarines' by the Royal Navy.

Below: Since the mid-1970s the Valiants have carried the Mk 24 Tigerfish wire-guided torpedo (1). Originally this was available only as an antisubmarine weapon, and was complemented by the elderly Mk 8 anti-ship torpedo, but the Mod.2 variant of Tigerfish currently in service has a dual-purpose capability. The Valiants are currently being retro-fitted to fire the Sub-Harpoon anti-ship missile (2). They can also launch Marconi Stonefish (3) and British Aerospace Sea Urchin (4) mines from their torpedo tubes.

HMS *Valiant* (S 102)

steel gives the submarine a diving depth of 1,000ft (300m). At the forward end of the boat there is a two-deck layout housing the control and accommodation spaces, and a smaller cylinder housing the torpedo stowage and handling arrangements. The after end of the submarine is occupied exclusively by the reactor and machinery spaces. *Dreadnought*, like the US Skipjacks, incorporated little or no sound insulation. In the Valiants, however, the main turbines and gearing were mounted on a raft insulated from the hull by flexible mountings. A novel feature of the class was the inclusion of a separate propulsion motor, located abaft the geared turbines and coupled directly to the single shaft. This arrangement permits three possible propulsion modes. For moderate speeds, such as might be required for support of a task force or convoy, power is provided by the geared turbines and the raft is isolated from the hull. At very high speeds, which would be used for interception or evasion, the raft is locked into place. And at creep speed, during barrier patrol or other such ASW operations, the boat is powered by the independent electric motor. A 112-cell battery, charged by a Paxman diesel generator, provides emergency power in the event of reactor failure. Unlike their US Navy counterparts, the British SSNs have their forward hydroplanes mounted close to the bow; they fold upwards to enable the submarine to come alongside without sustaining damage.

Armament: There are six bow torpedo tubes of the standard 21in (533mm) diameter, and the torpedo handling room has stowage capacity for 20 reloads. Early units of the class commissioned with the elderly Mk 8 anti-ship torpedo and the Mk 20 acoustic-homing antisubmarine torpedo. From 1970 onwards the latter was superseded by the Mk 23, essentially a Mk 20 with wire guidance. *Churchill*, the third unit of the class, was the first to be fitted to fire the Mk 24 Tigerfish wire-guided antisubmarine torpedo, which entered service in 1974. The guidance systems of the early models of Tigerfish were not particularly well-suited to anti-ship operation, and reports that the Mk 8 torpedo had been taken out of service in the early 1970s were conclusively refuted when the submarine Conqueror used two Mk 8s to despatch the Argentinian cruiser General *Belgrano* in 1982 during the Falklands conflict. *Churchill* evaluated both the Sub-Harpoon anti-ship missile and the US Mk 48 Mod.3 torpedo prior to the adoption of the former by the Royal Navy. *Courageous* was the first of the class to deploy Sub-Harpoon operationally, in 1981, and the other boats are currently being retro-fitted with the missile.

Electronics: As completed the Valiants had an advanced sonar outfit comprising a Type 2001 low-frequency active/passive array (strapped around the outside of the 'chin' of the submarine), a Type 2007 passive flank array, and a Type 197 intercept array. A well-equipped attack centre was based around the DCA Action Information Organisation and Fire Control System. Beginning with *Courageous* in the late 1970s, the class began a series of long refits during which major updates were made to the electronics. The Type 2001 chin array is being replaced by the Type 2020 electronically scanned array which entered service on the Tratalgar class, and a Type 2026 towed hydrophone array is being fitted. These modifications will be extended to all units of the class except *Worspite*.

Construction: Five submarines of the Valiant class were built for the Royal Navy between 1966 and 1971 at the Vickers Shipyard, Barrow-in-Furness and at Cammell Laird, Birkenhead. The programme was delayed by work on the Polaris submarines of the Resolution class.

Right: *Warspite*, the second unit of the class to be completed. The Valiants have a more curved hull-form than later British nuclear-powered submarines and a taller, more angled fin, and unlike their US Navy counterparts they have their forward hydroplanes mounted close to the bow. The current update programme includes provision of a Type 2026 passive array and modifications to the fire control electronics to enable these submarines to fire Sub-Harpoon.

Victor class

Origin: USSR, first unit completed 1968
Type: Attack submarine, nuclear-powered (SSN)
Displacement: Victor I: 5,100 tons submerged
Victor II: 5,700 tons submerged
Victor III: 6,300 tons submerged
Dimensions: Victor I: length 312ft (95m); beam 33ft (10m); draught 23ft (7m)
Victor II: length 328ft (100m); beam and draught as Victor I
Victor III: length 348ft (106m); beam and draught as Victor I
Propulsion: One/two pressurized water-cooled reactors driving geared steam turbines; 1 shaft (see remarks); 30,000shp for 29-30kt
Complement: Victor I & II: 80
Victor III: 85
Background: In 1960 the first US Navy ballistic missile submarine, *George Washington* (SSBN-598), entered service. This new development was to compel the Soviet Navy to rethink its maritime strategy. Antisubmarine warfare, which had previously been neglected, assumed a new importance, and the Soviet Navy embarked on an ambitious surface ship construction programme headed by the Moskva-class antisubmarine cruisers; almost simultaneously the first Soviet nuclear-powered submarine with a primary antisubmarine mission, the Victor, was laid down. Fitted with a newly developed LF active/passive bow sonar, the Victor was initially charged with hunting down Western SSBNs. In theory this meant that the Victor would attempt to pick up the SSBN as it sortied from its home port, and would shadow it throughout its patrol. These tactics appear to have met with little success, and in the early 1970s they were superseded by a 'pro-submarine' mission in support of the Soviet Navy's own SSBNs. With the advent of the Delta class and the 4,250nm (7,800km) SS-N-8 ballistic missile, Soviet SSBNs would increasingly operate in defended 'bastion' areas where they would be protected by a combination of surface ships, aircraft and submarines like the Victor. In 1972 the first of a new variant, Victor II, entered service; it introduced the SS-N-15 nuclear-tipped antisubmarine missile to the Soviet Navy. In 1978 this variant was superseded in turn by the Victor III, which was fitted with improved sensors, and large-diameter torpedo tubes which enabled it to fire the SS-N-16 antisubmarine missile.

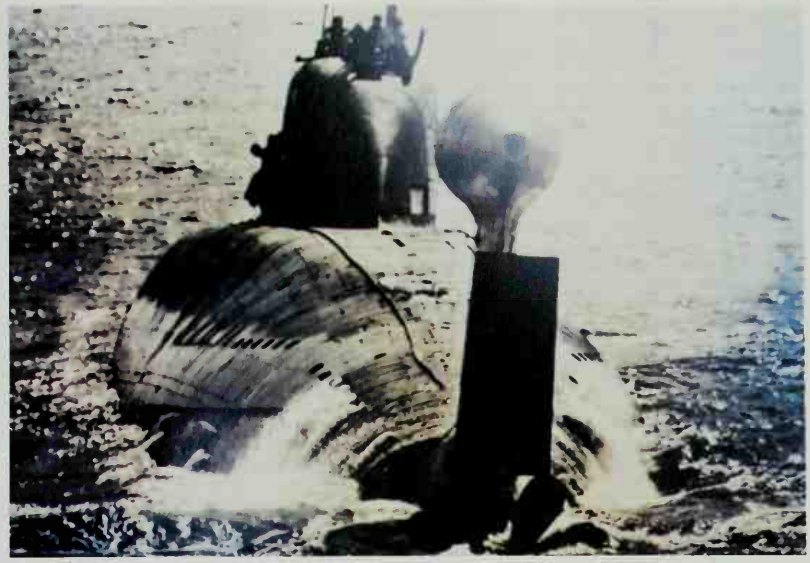
Design: The Victor was a completely new design which owed little to the only previous Soviet SSN, the November, its tear-drop hull being 50ft (15m) shorter and slightly broader. An improved type of nuclear reactor was fitted, and some attempt was made to quieten machinery noise. From the Victor II onwards, the hull casing was covered with an anechoic rubber sheathing. The six torpedo tubes are all forward, the 16in (400mm) stern tubes of earlier Soviet nuclear boats being abandoned in favour of cruciform tail surfaces. The Victor was the first Soviet submarine with a single shaft. The Victor I and II variants are reported to have a single five-bladed propeller, with two small auxiliary propellers for manoeuvring. However, the Victor III has an unusual eight-bladed propeller, comprising two tandem four-bladed propellers which co-rotate. Each of the two later variants of the class shows an increase in length over its immediate predecessor: in both cases an additional hull section has been inserted between the fin and the bow, indicating that an increase in space was required for new weapons and fire control systems.

Armament: The Victor I was initially armed only with conventional anti-ship and acoustic-homing antisubmarine torpedoes, but the Victor II variant introduced the SS-N-15 antisubmarine missile into Soviet service. The missile is similar in conception to the US Navy's SUBROC. It has a nuclear warhead to compensate for guidance inaccuracies, and has a maximum range estimated at 21nm (40km). It can be fired from a standard 21in (533mm) torpedo tube, and the necessary fire control equipment may therefore have been retro-fitted in some Victor Is. The SS-N-16 antisubmarine missile carried by the Victor III did not enter service until about 1980. It carries a homing torpedo payload in place of a nuclear warhead, and is therefore of greater diameter than the SS-N-15. The SS-N-16 is fired from a special 26in (650mm) tube which can also handle the new Type 65 wake-homing torpedo.

Below: The Victors can fire a wide variety of weapons from their six bow tubes. In the Victor I the tubes are thought to be of uniform 21in (533mm) diameter; these can fire the SS-N-15 antisubmarine missile (1), which has a nuclear warhead, and an antisubmarine homing torpedo (2) thought to have entered service in the mid/late-1960s. In place of each of the torpedoes and missiles, two mines (3) can be accommodated in the racks. In the Victor II and III some of the torpedo tubes are of 26in (650mm) diameter, enabling them to fire the SS-N-16 antisubmarine missile (4), which carries a small homing torpedo, and the high-performance Type 65 anti-ship torpedo (5), which is thought to home on the wake created by a surface ship.

Electronics: All three variants of the Victor are fitted with a large active/passive LF bow array capable of detecting hostile ships at considerable distances under favourable sonar conditions. In addition, the Victor III can deploy a towed hydrophone array from the teardrop-shaped pod atop the tail-fin. The sensor masts are standard for their period and comprise search and attack periscopes, a Snoop Tray surveillance radar, Brick Pulp ESM, Park Lamp VLF reception, and aerials for HF and VHF communications. The Victor III also has Pert Spring for satellite communications. Both the Victor II and the Victor III have twin hatches abaft the fin for a VLF communications buoy.

Construction: Sixteen Victor Is were completed by the Admiralty Shipyard, Leningrad, between 1967 and 1975. Seven Victor IIs were completed by the same shipyard between 1972 and 1978. The first Victor III was completed in 1978, and since that time a further 20 have entered service, with a second production line being opened up at Komsomolsk in the Pacific. The Victor is now being phased out in favour of the similar, but slightly larger, Akula.



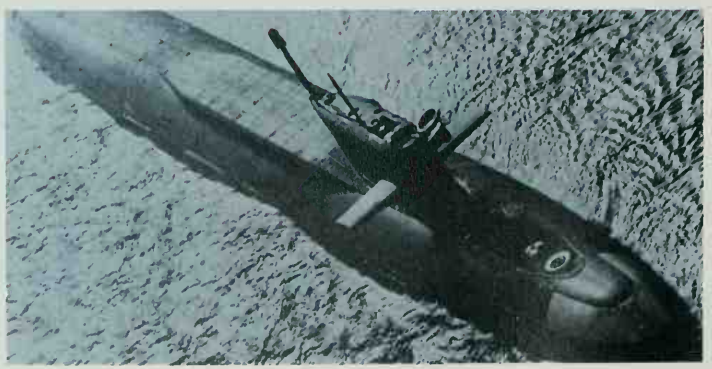
Above: A submarine of the Victor III class in trouble off the East Coast of the United States. Note the distinctive pod atop the tail-fin, thought to house a towed passive hydrophone array, and the co-rotating four-bladed propellers.

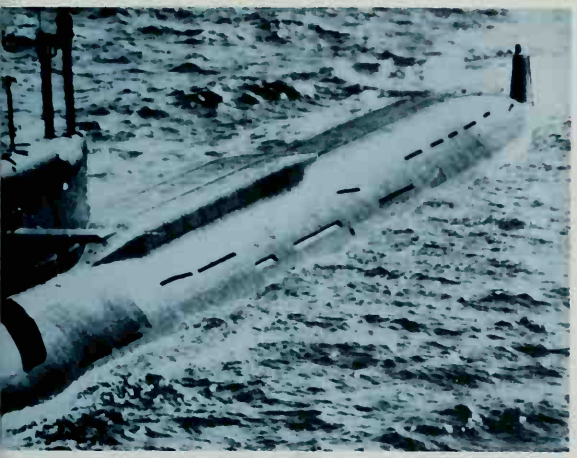
Right: An early view of a Victor I running on the surface. These are thought to have been the first Soviet submarines designed primarily to hunt other submarines and a number of innovatory features were incorporated in the design, including Western-style cruciform tail surfaces and a single propellor shaft. The Victor proved so successful that production continued for more than 15 years, and the design has only recently been superseded by the Akula.

Yankee class

Origin: USSR, first unit completed 1967
Type: Ballistic missile submarine, nuclear-powered (SSBN)
Displacement: 8,000 tons surfaced; 9,600 tons submerged
Dimensions: Length 430ft (130m); beam 39ft (12m); draught 29ft (9m)
Propulsion: Two pressurized water-cooled reactors driving geared steam turbines; two shafts; 35,000shp for 27kt max
Complement: 120
Background: When the Strategic Rocket Forces were formed in 1960 the Soviet Navy's land attack mission was suspended pending the development of powerful land-based ICBMs. Construction of the Hotel-class SSBNs was terminated after only nine had been laid down, as was construction of the Golf-class SSB. By 1964, however, the Navy had regained a limited nuclear land attack role and the first of a new type of SSBN, the Yankee, was on the slipways. The SS-N-6 missile with which these submarines were equipped could be launched from under water and had almost twice the range of its immediate predecessor, the SS-N-5. Nevertheless, the Yankees would still need to patrol relatively close to the East and West coasts of the United States in order to target all the major cities. This involved lengthy transits to their patrol areas, and Yankees serving with the Northern Fleet would have to pass through the NATO antisubmarine barrier in the Greenland/Iceland/United Kingdom (GIUK) Gap. A number of theories have been developed to explain the construction of these submarines. Some commentators have advanced the view that the Yankees have a second-strike mission, and at the start of a conflict would be held back in defended sea areas ('bastions') for nuclear war-fighting. Another possible explanation is that forward-deployed Yankees would target specifically naval installations such as ports and airfields.
Design: The Yankee belongs to the same generation as the Victor-class SSN and the Charlie-class SSGN; the hull-form and propulsion plant are therefore more advanced technologically than those of first-generation Soviet nuclear boats. Soviet missile technology had made comparable advances by the early 1960s, and in spite of its markedly superior performance the SS-N-6 missile was significantly smaller than the SS-N-4 Sark missile for which the Hotel and Golf were designed. There was therefore no longer any

Below: An overhead view of a Yankee I, showing clearly the raised section of casing housing the SS-N-6 missiles. Note the fin-mounted diving planes and the distinctive sonar 'window' around the top of the bow. The unit depicted is one of several with an angled base to the fin.





Above: A Yankee I running on the surface. Note the large rectangular apertures along the sides of the hull casing: these are evidence of double-hull construction, which continues to be favoured by Soviet designers. Thirty-four Yankees were completed for the Soviet Navy between 1967 and 1974.

need to accommodate the missile tubes in the fin, a design feature which in earlier classes had restricted the number of missiles to three. For the Yankee the Soviets adopted the arrangement standard in US Navy SSBNs (hence the NATO name for the class), with 16 missile tubes in two rows of eight abaft the fin. Another feature copied from the US boats was the hydroplane and rudder arrangement; the forward planes were mounted on the fin for the first time in the Soviet Navy, and combined with cruciform control surfaces aft. The major difference between the Yankee and Western SSBNs of the period was Soviet persistence with double-hull construction and twin-shaft propulsion. The need to transit sea areas dominated by NATO antisubmarine forces appears to have influenced the Soviets in favour of relatively high speed for the Yankee, which has more than twice the installed horsepower of contemporary Western SSBNs. A prototype conversion, the Yankee II, was modified in the mid-1970s to fire 12 SS-NX-17 missiles, but the SALT II Treaty prevented further conversions.

Armament: The SS-N-6 missile is around 38ft (11.5m) long and has a diameter of 5ft 5in (1.65m). The earliest variant of the missile carried a single nuclear warhead of about 1MT and had a maximum range of 1,300nm (2,400km). It was followed in 1972 by a Mod.2 variant with a range of 1,600nm (2,950km). A Mod.3 variant, which may have entered service one year later, had similar range but carried two reentry vehicles. The SS-NX-17 evaluated in the single Yankee II conversion is a somewhat larger missile, with a length of perhaps 40ft (12.5m) and a diameter similar to that of the SS-N-8 (hence the reduction from 16 to 12 missile tubes). It is reported to be more accurate than the SS-N-6 and is the only Soviet ballistic missile apart from the SS-N-20 to have solid-fuel propulsion. The Yankees have six bow tubes for standard 21in (533mm) torpedoes. Both long anti-ship and short antisubmarine torpedoes can be fired

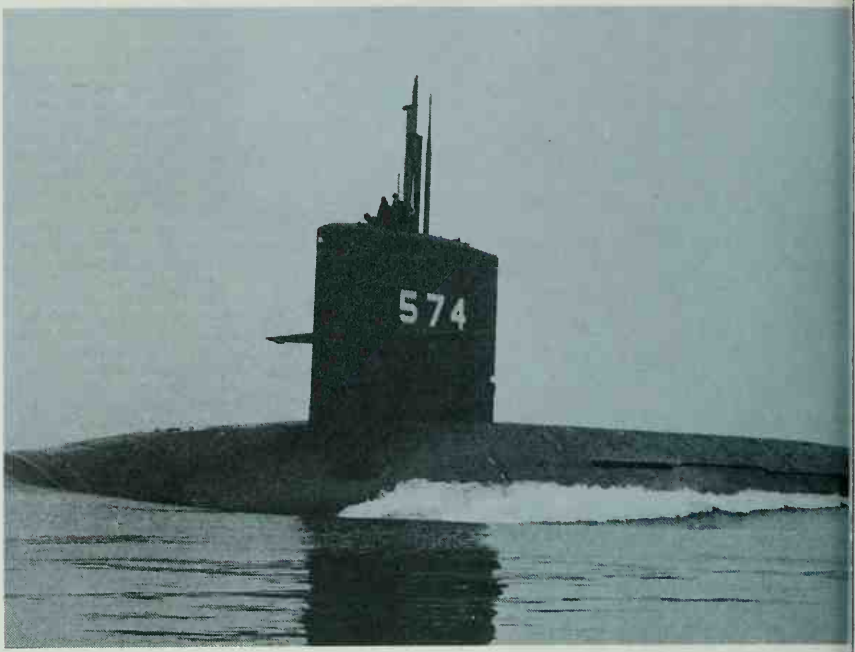
Electronics: The Yankee has a large active/passive bow sonar with a distinctive wrap-around 'window' some 13ft (4m) deep. Mast-mounted sensors are identical to those of the Victor and Charlie classes, but there is also a Cod Eye radio sextant for navigational accuracy housed in the top of the fin.

Construction: The first Yankees were completed in 1977, and the programme was then accelerated, with parallel construction at Severodvinsk in the Arctic and Komsomolsk in the Pacific. A total of 34 submarines of the class were in service by 1974, but of the earlier Yankee Is have now had their missile tubes deactivated to enable the Soviets to stay within SALT II Treaty limits. One of these deactivated boats was recommissioned in 1982 to serve as a trials platform for a new long-range land-attack cruise missile, the SS-NX-24.

Left and below: The launch tubes of the Yankee house 16 SS-N-6 ballistic missiles (1). These are thought to be a mix of the Mod 2 variant, which has a range of 1,600nm (2,950km) and a single 1MT nuclear warhead, and the Mod 3, which has a similar range but carries two smaller reentry vehicles. A single unit of the class, designated Yankee II, was modified to carry 12 SS-N-17 missiles. Conventional long anti-ship torpedoes (2) of 21in (533mm) diameter can be fired from the six bow tubes, and there is probably also a shorter 533mm homing torpedo (3) for use against submarines.

Yuushio class

Origin: Japan, first unit completed 1980
Type: Attack submarine, diesel-powered (SS)
Displacement: 2,200 tons surfaced
Dimensions: Length 250ft (76.2m); beam 32ft 6in (9.9m); draught 24ft 6in (7.5m)
Propulsion: Diesel-electric drive on one shaft; two Kawasaki-MAN V8/V24-30 AMTL diesel generators, each 1,700bhp; one Fuji electric motor; 3,400bhp for 13kt surfaced, 7,200hp for 20kt submerged
Complement: 80
Background: The first fleet submarines to be built postwar for the Japanese Maritime Self-Defence Force (JMSDF) were the five units of the Ooshio class, which were completed between 1965 and 1969. The Ooshios were of conservative design, with a traditional hull-form, two shafts, and six bow and two stern tubes. They were quickly overtaken by new technology, and were decommissioned in the early 1980s. The Ooshio was succeeded by the Uzushio, a completely new type incorporating all the latest features of US Navy construction. The Uzushio was the first Japanese submarine with an 'Albacore' hull-form, and an internal layout similar to that of contemporary US SSNs was adopted, with the bow occupied by a large passive sonar array and six torpedo tubes angled out amidships. The Uzushio was designed for high underwater speed, and proved particularly sucessful; seven units were



Above: *Mochishio*, the second unit of the class. Seven submarines of this type have so far been completed, and a further seven are building or projected. Based, like their immediate predecessors of the Uzushio class, on the US Barbel design, the Yuushios have a large sonar array in the bow with the six torpedo tubes angled out beneath the fin, as in contemporary US Navy SSNs. They are large, sophisticated boats, with good endurance.

Right: The Yuushios are fitted with six 21in (533mm) torpedo tubes. They are angled out in two banks of three beneath the fin in the manner of US Navy attack boats, which also have a sonar occupying their bows. The Japanese Maritime Self-Defense Force currently has in service the US Mk 48 heavyweight dual-purpose torpedo and the 'short' US Mk 37C antisubmarine torpedo (1). The Mk 48 will eventually be superseded by a new high-performance torpedo of Japanese design and manufacture, the GRX-2 (2). The fifth unit of the class, *Nadashio*, was fitted from the outset to fire the Sub-Harpoon anti-ship missile (3), which will be retro-fitted to earlier boats.

completed between 1971 and 1978. The Yuushio type which followed is essentially an improved Uzushio, designed for deeper diving and with an improved electronics outfit.

Design: The Yuushio has a hull-form reminiscent of the US Barbel. Unlike its US Navy counterparts, however, the Japanese boat has double-hull construction, the pressure hull being framed externally, and high-tensile NS-90 steel has superseded the NS-60 steel employed in the construction of the Uzushio class, thereby increasing diving depth from 650ft (200m) to 1,000ft (300m). The maximum diameter of the pressure hull is amidships, where there is a three-deck layout. Forward of the fin there is a smaller cylinder in which the six torpedo tubes are located. There are six tubes, disposed as two vertical banks of three and angled out at 10 degrees to the submarine's axis, leaving the bow section free for the large passive sonar array. Immediately abaft the tubes there is a stowage room on three levels, with the reloads in line with the tubes. Above the stowage room is a combined control and attack centre, and accommodation for the officers and men is abaft the control centre and the torpedo stowage room respectively, arranged on two levels. The lower deck level is occupied exclusively by the submarine's batteries. The after section houses the propulsion and auxiliary machinery spaces together with the switchboard. The diesel engines are manufactured by Kawasaki under licence from MAN (FRG). The powerful electric motor, which can produce a maximum of 7,200hp for an underwater speed of 20 knots, was designed and manufactured by Fuji. The control surfaces of both the Uzushio and Yuushio classes are patterned on those of contemporary US Navy SSNs, with the forward hydroplanes mounted on the fin and cruciform tail surfaces forward of a single seven-bladed propeller. The Japanese boats have an automated steering system which features automatic control of both depth and bearing.

Armament: The six torpedo tubes are of standard 21in (533mm) diameter. No details are available of weapons capacity, but the layout of the stowage room suggests 12-15 full-length torpedoes shared between the three levels. It is reported that the JMSDF operates both the US Mk 48 wire-guided heavyweight torpedo, which can be used against surface ships or submarines, and the Mk 37C short antisubmarine torpedo. Two of the latter can be accommodated in place of one of the larger Mk 48s. A new high-performance torpedo of Japanese design and manufacture, the GRX-2, is currently under development. The fifth unit of the class, Nodoshio, which was completed in March 1984, was the first to be fitted to fire the Sub-Harpoon anti-ship missile, which will eventually be retro-fitted in earlier boats.

Electronics: The sonar outfit of the Uzushio and Yuushio classes is based on the ZQQ-4 passive array located in the bow. The ZQQ-4, apparently a Japanese development of the US Navy's BQS-4, comprises three circular transducer arrays stacked one above the other. This arrangement serves to reduce the vertical beam of the sonar and to reduce the signal to noise ratio. The ZQQ-4 is complemented by an SQS-36J active (attack) sonar, and the electronics outfit is completed by a full array of mast-mounted sensors, which include attack and search periscopes, a ZPS-6 surveillance radar, and numerous masts for electronic warfare (EW) and communications.

Construction: By the end of 1986 seven units of the Yuushio class had been completed at the shipyards of Mitsubishi (Kobe) and Kawasaki (Kobe), with seven further units building or projected. A follow-on design, incorporating an advanced weapon control system by Hitachi, is currently being prepared.

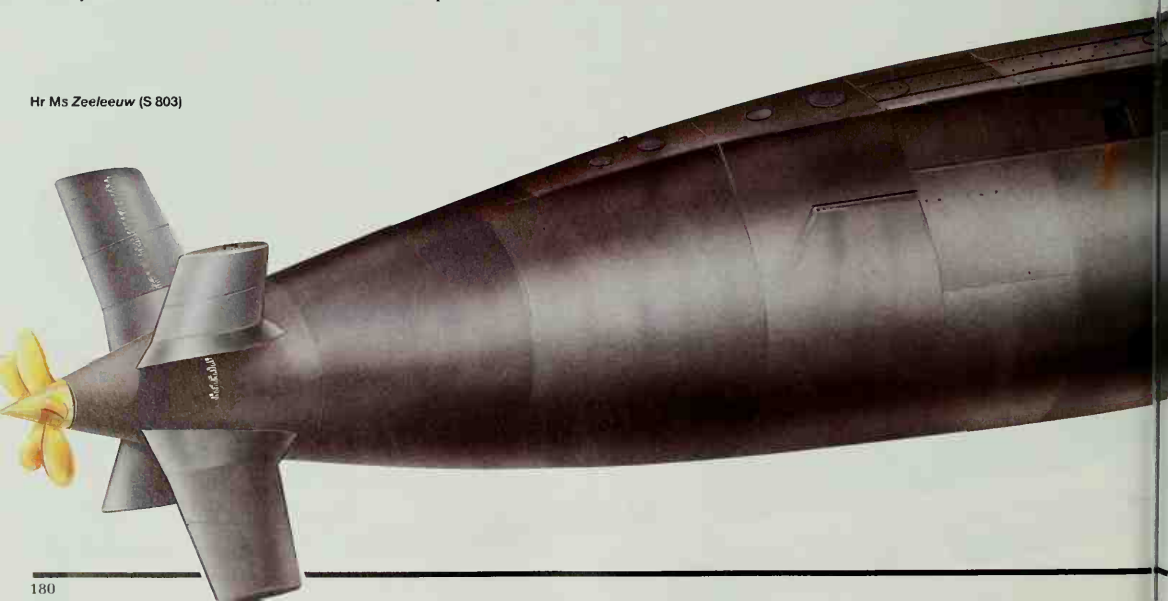
· *Yuushio* (SS 573)

Zeeleeuw class

Origin: Netherlands, first unit to complete 1989.
Type: Attack submarine, diesel-powered (SS).
Displacement: 2,450 tons standard; 2,800 tons submerged.
Dimensions: Length 222ft (67.7m); beam 28ft (8.4m); draught 23ft (7m).
Propulsion: Diesel-electric drive on one shaft; three SEMT-Pielstick 12 PA 4V 200 diesel generators (see remarks); one Holec electric motor; 3,950bhp for 12kt surfaced, 5,430hp for 21kt submerged.
Complement: 50.
Background: The Walrus class was designed in the late 1970s to replace the elderly triple-hull boats of the Dolfin class. Initially, the design was to have been based closely on that of the two submarines of the Zvaardvis class completed in 1972. However, as detailed design work proceeded so many modifications were incorporated that the Walrus became a separate type. In order to preserve the design teams and labour force at the RDM shipyard construction was brought forward, and the first steel was cut even before the contract for the first boat was signed in June 1979. However, a change in the Netherlands Navy specification, requiring a 50% increase in diving depth, led to major redesign and consequent delays in the construction of the first two boats. A second pair was ordered in January 1984, and a third pair his projected.
Design: Like the preceding Zvaardvis class, the Walrus has an 'Albacore' hull-form based on that of the US Barbel design. The forward hydroplanes are mounted on the fin, as in US Navy submarines, but the cruciform after control surfaces of the Zvaardvis have been superseded by 'X'-planes on the Swedish model (see Näcken). The adoption of high-tensile French MAREL steel for the pressure hull necessitated a reduction in the number of welded joints and hull apertures. The consequent increase in diving depth to 985ft (300m) brought further design modificatfons, including changes in the torpedo launching systems, a pressurized fuel system, a 'wet' exhaust system, more sophisticated hydraulics and additional emergency blowing systems. The pressure hull comprises a large-diameter cylinder amidships, with smaller-diameter cylinders fore and aft. The hull configuration is therefore an unusual mix of single- and double-hull construction. The larger cylinder amidships allows for a spacious three-deck layout with the control centre and officer accommodation on the upper deck and the accommodation for the crew on the second deck. The lower deck is occupied by the three 148-cell battery banks. The smaller cylinder forward houses the torpedo stowage room, while the smaller cylinders aft house the propulsion units and auxiliary machinery. In the forward machinery compartment are the three diesel generators, which are disposed abreast on a resiliently-mounted raft. The central compartment is divided into two decks, with the switchboard on the upper level and the auxiliary machinery below. The third compartment houses the main electric motor. The latter is a double-armature Holec model of Netherlands design and manufacture, but for the diesels the Dutch had to turn to the French, as the Werkspoor model which was employed in the Zvaardvis class was no longer in production. However, the second pair of submarines in this class will have the Brons-Werkspoor O-RUB 215X12 diesel currently under development. Control of the machinery is highly automated, and this has made possible a

Above: The Zeeleeuw class is a development of the Zwaardvis design depicted here which was based in turn on the US Barbel. The latest Dutch boats are all of modern design, employing an 'Albacore' hull-form, and the forward hydroplanes are mounted on the fin in the manner of their US counterparts.

Hr Ms *Zeeleeuw* (S 803)

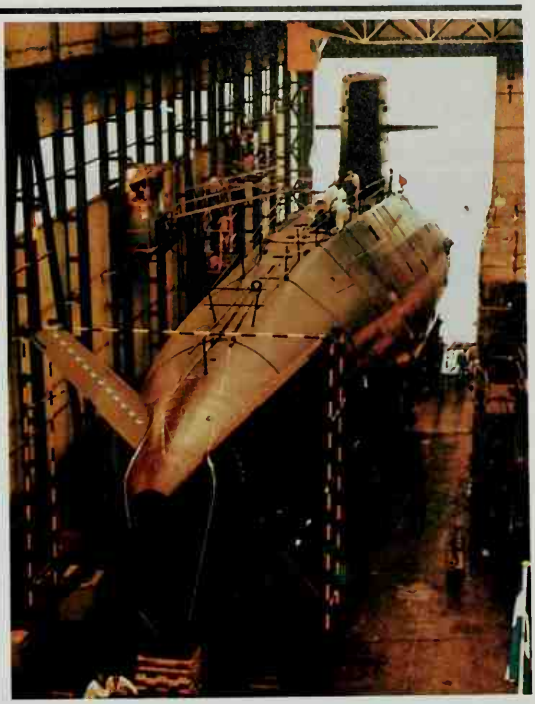


reduction in the complement to only 50 men.

Armament: The four 21in (533mm) bow tubes are of the positive discharge 'water-slug' type, which enables them to fire torpedoes at any depth. The capacious torpedo stowage room has a maximum capacity of 20 torpedoes or missiles. The torpedoes currently in service with the Royal Netherlands Navy are the Northrop NT-37C and -37D antisubmarine models and the US Mk 48 Mod.4 heavyweight torpedo. The improved NT-37E is currently being purchased, and it is envisaged that the Walrus class will also fire the Mk 48 Mod.5 ADCAP when the latter becomes available. They will be fitted from the outset with the necessary fire control facilities for the Sub-Harpoon anti-ship missile.

Electronics: The electronics outfit represents a marked advance on the earlier Zwaardvis class. The large Octopus active/passive circular bow array is based, like the Type 2040 currently being fitted in the British Upholder class (q.v.), on the Thomson-CSF Eledone sonar. The other major sonar array will be the British Type 2026 towed hydrophone array. The intercept sonar will be the Passive/Active Range and Intercept Sonar (PARIS) developed jointly by France, Britain and the Netherlands, which first entered service in 1978. The Walrus class will have a SEWACO VIII computer-based Action Information Organisation and Fire Control System. The Sperry Mk 29 Mod.2A inertial navigation system will be fitted, together with a NAVSAT (Navigation Satellite) receiver.

Construction: Completion of *Walrus* has been delayed following a serious fire at the RDM Shipyard, Rotterdam, and the class has been renamed Zeeleeuw after the second boat, which will complete on schedule in 1989. The third and fourth boats will follow in 1992 and 1994 respectively.



Above: The most notable innovation of the Walrus (now Zeeleeuw) class is the adoption of X-planes in the place of the conventional cruciform tail surfaces. X-planes give finer control of depth and bearing and permit 'bottoming'.

1

2

Above: The Zeeleeuw class will have four 21in (533mm) bow torpedo tubes of the 'water-slug' type. The Royal Netherlands Navy currently has in service the US Mk 48 heavy-weight dual-purpose torpedo (1) and the NT-37C/D/E short antisubmarine torpedo. These boats will also be fitted from the outset with the necessary fire control facilities for the Sub-Harpoon anti-ship missile (2). Besides the four weapons carried in the tubes, there is stowage for 16 reloads.

Underwater Warfare

Tactics

David Miller

Below: The Italian destroyer *Artigliere* breaks in two and sinks after being hit by a Whitehead A.184 heavyweight wire-guided torpedo in May 1983.

Introduction

A submarine's mission profile generally follows one of three mainpatterns, depending on its type and role, but all submarines must start by leaving base on or very near the surface, a manoeuvre which is almost always detectable by direct visual means, radio intercept – for example, of harbour control frequencies – or satellite observations. Unless they are confined to an area such as the Baltic they must then transit through the shallow waters of the continental shelf, where they are relatively easy to detect, before reaching the open ocean. And Soviet submarines must pass through choke points, where detection is particularly easy. In the deeper ocean, however, the three missions diverge.

When it is clear of the continental shelf a ballistic missile submarine will usually go deep and travel reasonably fast to its patrol area, taking every precaution to ensure that it is not being trailed by SSNs; in its patrol area it will cruise at about three knots, hiding itself from detection by varying its depth to match prevailing oceanic conditions. However, it must expose itself to the risk of detection when it needs to communicate with its national command authority or update its inertial navigation system. Nuclear powered attack submarines, being faster and more agile, operate at greater depths, but they too must communicate from time to time with their base or with cooperating task groups.

Conventionally powered submarines must surface as a matter of routine to run the diesels that recharge their batteries, and to expel the diesel exhaust. They can do so by exposing only the head of a schnorkel tube, but even that is a relatively easy target for modern radars and infra-red sensors, and the exhaust fumes can be detected by the sniffers mounted on most types of anti-submarine aircraft.

In considering submarine tactics there is one unique factor that should always be borne in mind, namely the solitary nature of the submariner's existence and fight for survival. In almost every other type of warfare units operate in groups, manoeuvring in cooperation and in regular communication with each other, with flanking and supporting units and with superior headquarters. The submariner, on the other hand, can, within certain well defined limits, receive communications from outside and communicate with his base, and he may, in some circumstances, operate in very loose coordination with other surface or submarine units, mainly on the basis of being given an exclusive zone within which he can operate, but in the final analysis he is on his own, and must fight and survive in isolation.

Above: Mk 46 torpedo launched from a Mk 32 launcher on board a destroyer. The effectiveness of surface warships against submarine targets is a subject of discussion in most navies; many hold that submarines and aircraft are the most effective platforms.

Left: Periscope view from HMS *Oberon* of a Westland Sea King dunking. ASW aircraft, both fixed- and rotary-winged, are very effective in the ASW role, especially when using passive sonar, as they are virtually undetectable by the submarine.

Top right: Royal Navy Lynx HAS.3 carrying two Mk 46 antisubmarine torpedoes. Such small shipborne helicopters have brought a much-needed enhancement to surface warships' ASW capabilities, though aircraft size is growing.

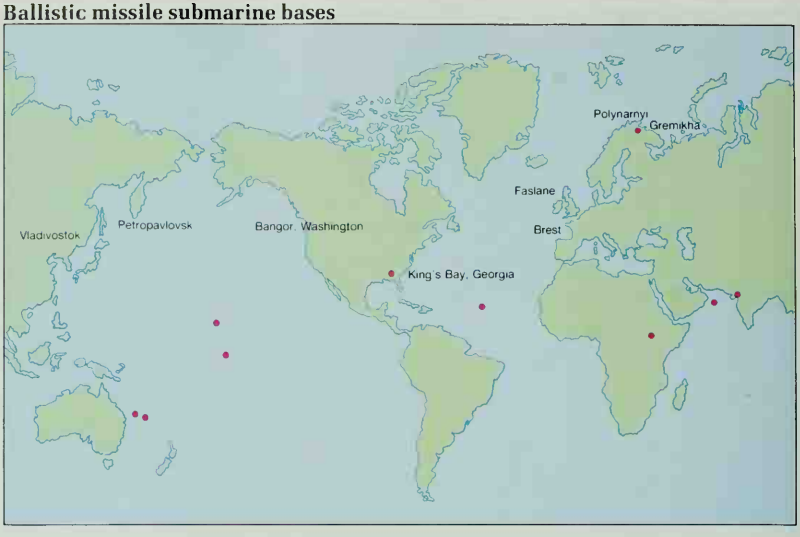
Right: The control room on board HMS *Trafalgar*, lead boat of the latest class of British SSN. The submarine provides a unique operational environment, being almost totally self-contained, and dependent on its own resources and capabilities for survival.

Submarine Tactics

The sole utility of ballistic missile submarines lies in their strategic capability and their tactical use must, therefore, be viewed in their strategic context. Since the 1950s US and (probably) Soviet strategic thinking has been based on the concept of a nuclear triad of long-range bombers and land-based and submarine-launched ballistic missiles, the last being the ultimate deterrent in that they provide an assured response to a first strike by ICBMs with a massive attack on the aggressor's cities. This strategic theory of deterrence was enhanced when both the USA and the Soviet Union had a proportion of their nuclear armouries deployed in such a way as to be immune to a first strike by the other side, but two factors suggest that this equation may be altered in the near future: the first is the dramatic increase in the accuracy of SLBM warheads; the second is the steady increase in the effectiveness of present-day anti-submarine warfare techniques.

The accuracy of a warhead dictates the role of the missile that launches it, since a highly accurate warhead can be used in a first strike attack on an opponent's ICBM silos while a less accurate warhead can only be used against unprotected area targets such as cities. The accuracy of the latest warheads on US and Soviet SLBMs is giving both sides at least the potential for a counter-force role, provided they are attacking fixed targets of known location. However, the deployment of the Soviet rail-transportable SS-X-24 and road-mobile SS-25, with their 6,250-mile (10,000km) ranges and ability to change locations, has negated the advances in US warhead accuracy.

Ballistic missile submarine bases

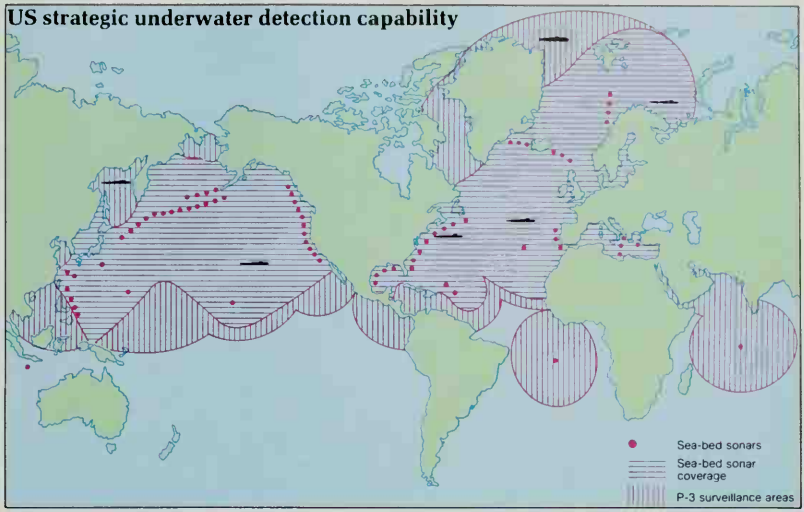


Above: Ballistic missile submarines seek the security of the ocean depths while on patrol, but must begin and end their missions at bases whose locations are known.

Right: Us DoD artist's depiction of a new Soviet submarine base. The underground pens whose entrances are clearly shown are designed to ensure the survivability of SSBNs.

Below: The British submarine base at HMS Dolphin, Gosport. Used by conventional submarines, this base is also the home of Flag Officer Submarines (FOSM), who commands the UK force.

Right: US strategic underwater detection capability, showing coverage given by sea-bed arrays such as SOSUS and land-based ASW aircraft. Tactical detection is the job of submarines, and ships.



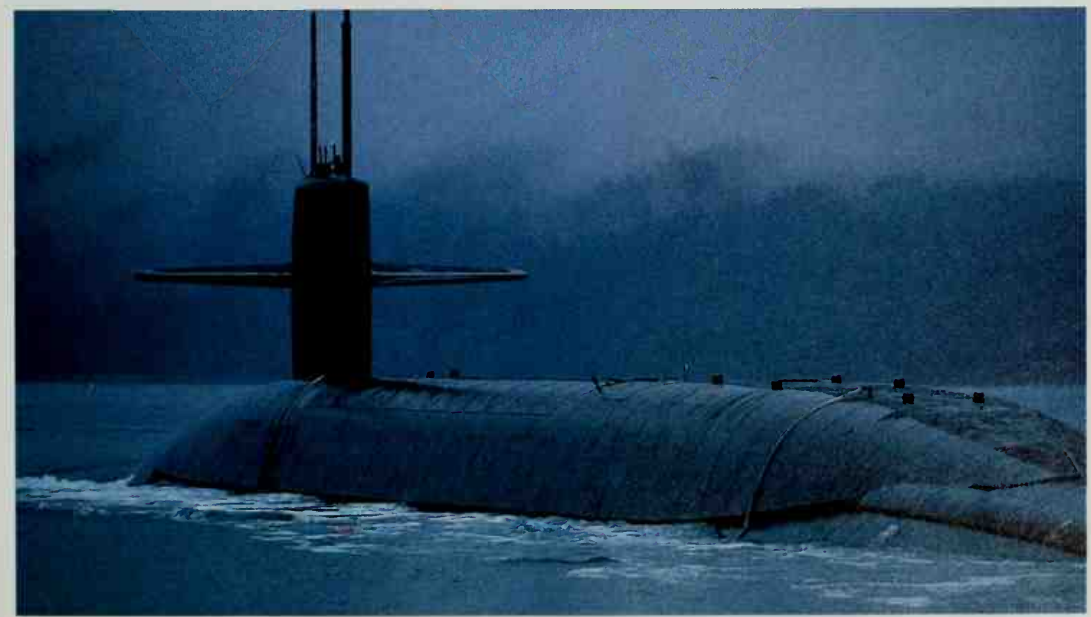
About a third of any naval force is in port at any one time for maintenance, repair, exchange of crews or major refit. Thanks to good management and reliable equipment the US Navy is able to keep 65 per cent of its Ohio class submarines at sea, an improvement on the figure of 55 per cent for the earlier classes, but the Soviet Navy seems to have more problems with its SSBN fleet and usually maintains no more than 15 boats on patrol at the same time; an alarm signal would be given to the US if large numbers of Soviet SSBNs were to put to sea in a short period. The British guarantee to keep an absolute minimum of one SSBN at sea at all times; the French have two; and one Chinese SSBN is probably deployed most of the time.

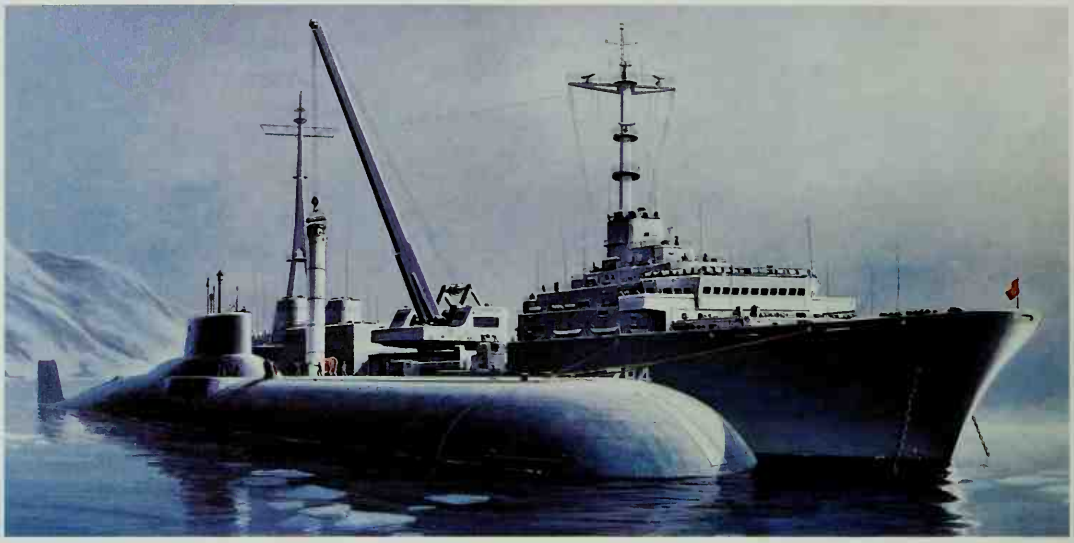
NATO's submarine-based strategic nuclear forces are unusual in that they are operated by three different navies, under three entirely separate national controls. Ballistic missile submarines are the most survivable of the current strategic nuclear systems when on patrol at sea, and there is no doubt that the US and Soviet SSBN forces pose the major second-strike threats to each other. The great strategic benefit of the British and French SSBN fleets is that they provide second and third nuclear decision-making centres in Western Europe, and their value is enhanced by the fact that each country has total control over its SLBM warheads. The USSR is, therefore, faced with the fact that if she were to attack Western Europe, even if the USA held back, the UK and France, either collectively or individually, could inflict an unacceptably destructive blow in retaliation. The strategic equation is further complicated for the USSR by the existence of another entirely independent nuclear force on its eastern flank.

Because of the special facilities required for ballistic missile submarines the location of their bases is easily identifiable and well known to potential opponents, and contemporary surveillance devices such as satellites and electronic monitoring enable their arrival and departure to be closely observed. Their departure is accompanied by characteristic and easily identifiable behaviour by escort vessels as they are checked for noise and magnetic signature and, in many cases, their clip-in towed arrays are fitted. Nor need such surveillance be necessarily confined to sophisticated space-based or electronic monitoring: British SSBNs, for example, have no choice but to leave their Scottish base at Faslane through the narrows at Rhu just north of Helensburgh, in full public view, while French SSBNs have a similar problem leaving Brest.

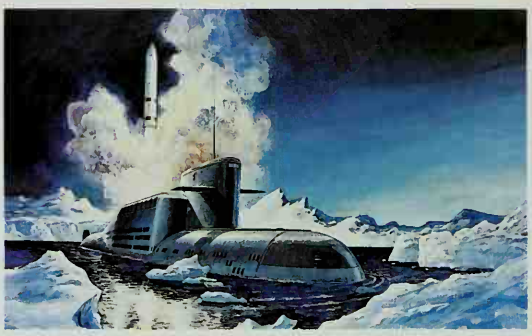
Having crossed the continental shelf a submarine is able to dive deep and seek shelter in the most suitable layers of the ocean. Early SSBNs, many of which are still in service, had to approach the surface periodically to update their inertial systems, exposing satellite communication antennas to do so, but more recent systems do not need such regular updates. Patrol areas depend on national strategies, geographical factors and, ultimately, the range of the missiles themselves.

Below: USS *Ohio* (SSBN 726) transits the Hood Canal en route to the western Trident submarine base at Bangor, Washington. There are two Trident bases; the other is at King's Bay, Georgia.





Above: *Alexander Brykin*, lead ship of a new class of Soviet SSBN tenders, as depicted by a US DoD artist. Missile replenishment in protected waters will greatly enhance survivability.



Left: A Soviet Delta IV surfaces in the Arctic to launch its SS-N-23 SLBMs. The Arctic has become a major potential battlefield and nuclear submarines roam under the ice-cap as a matter of routine.

Potentially hostile SSBNs are, inevitably, priority targets for opposing anti-submarine forces, even in peacetime. Even so, the dilemmas that would confront the commander of a ballistic missile submarine and a hostile attack submarine tracking it in time of tension – the one facing possible destruction of his deterrent load, the other confronted by the possibility of allowing it to be launched, and neither daring to break off the engagement to communicate with higher authority – are such that it would be a poor navy that did not have standing procedures to deal with the eventuality.

SOVIET STRATEGY

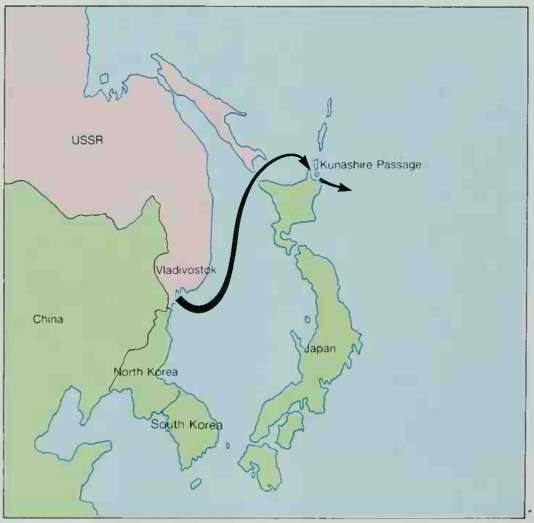
It seems clear that the Soviet Navy, if not the Soviet leadership, regards its ballistic missile submarine fleet as its most important single naval asset, just as it regards the US Navy's SSBN fleet as one of the most critical threats to its own homeland. It would also appear that the Soviet surface fleet has been designed with the primary task of protecting the SSBN fleet, rather than conducting independent forays into the North Atlantic which may nevertheless remain as a secondary task.

The Soviet Navy's early SSBNs, the Yankees, carried missiles whose range necessitated patrols close to the North American seaboard. Many are still in service, as was demonstrated all too clearly as recently as October 1986, when a Yankee was forced to surface following a catastrophic explosion in one of its SS-N-6 missiles some 600nm due north of Bermuda and thus some 750nm from New York and a similar distance from Washington, DC, both well within the 1,600nm range of its missiles. Although the Yankees are inherently vulnerable so close to the US mainland, the very short flight-time of their missiles enables them to threaten time-urgent targets such as the Strategic Air Command bomber bases on or near the Atlantic coast.

Other Soviet SSBNs are concentrated in two areas: the Sea of Okhotsk in the Far East and the Barents Sea in the west of the USSR. The US Navy and its allies are consequently forced to send submarines, surface warships and anti-submarine aircraft into these Soviet-dominated areas.

The original western Soviet SSBN base at Polynarnyi, on the Kola Peninsula, caters for the Yankee and earlier Delta class submarines but appears to be too small for the Typhoon class boats, and a totally new base for them, with protective pens blasted out of the adjacent cliffs, is being built at Gremikha. The Soviet SSBNs in the Far East are based at Petropavlovsk on the Kamchatka Peninsula and at Vladivostok.

Soviet Pacific Fleet Pacific exit



Above: Soviet submarines leaving Vladivostok are forced to transit the Sea of Japan and the Kunashir Passage between Kunashir Island and Hokkaido before they can reach the Pacific. This is one reason why the Soviets retain the Kurile Islands so tenaciously.

US AND ALLIED STRATEGY

The US Navy's ballistic missile submarine fleet is armed with a mix of Poseidon and Trident missiles. With the shorter ranged Polaris and Poseidon missiles some elements of the fleet had to be forward based at Rota in Spain and Holy Loch in Scotland, but with the introduction of Trident it has become possible to pull back to

Above: Crewmen in the control room of USS *Ohio*. Ballistic missile submarines form part of the strategic deterrent, and their crews must face the daily possibility that they may be called on to unleash a nulear holocaust.

Below: HMS *Resolution*, one of the Royal Navy's four current ballistic missile submarines. The British strategic nuclear capability is a major domestic political issue, and while a new class of SSBN is already building at the Vickers yard at Barrow the future cancellation of the programme remains a possibility.

two bases on the coast of the continental USA: Bangor in Washington State and King's Bay, Georgia.

Little information has ever been given about US Navy SSBN patrol areas, but it can be assumed that with Trident and Poseidon missiles maximum use is made of their longer range to enable the submarines to patrol in the Indian, Pacific and Atlantic Oceans, at maximum range from Soviet ports to exacerbate the Soviet anti-submarine problem but still threatening the major industrial and population complexes in the European and Far Eastern USSR.

The British SSBN base is at Faslane, on the Gareloch, off the River Clyde. Four submarines carry out patrols of approximately 70 days each, and the role of their Polaris missiles is publicly stated to be to threaten counter-value strikes against industrial and civilian complexes in European USSR; as the missiles' range is around 2,895nm it can be assumed that their patrol areas will probably be in the northern and western Atlantic. The French SSBNs, based on Brest, are generally similar to their British counterparts and can be assumed to have a similar targeting policy.

CHINESE STRATEGY

China has one operational Xia class SSBN, three more under construction and a further two planned; each carries 12 CSS-N-3 SLBMs. It can be assumed that China's operational deployment policy will be similar to that of France and the UK, but until SLBMs of much greater range are developed only targets in the Soviet Far East can be threatened. There are some very high value strategic targets in this area, although none is critical to the survival of the USSR.

The consequence of China joining the SSBN club is that European USSR is threatened by three seperate nuclear forces, those of the USA, UK and France, and the Far East is threatened by the USA and China, thus adding to the strategic uncertainty facing the Soviet leadership and strengthening deterrence. Each of the other five nuclear powers is only threatened by the USSR. The location of the Chinese SSBN base has not been publicly announced, but is probably in the vicinity of Huludao on the Yellow Sea.

CRUISE MISSILE SUBMARINES

The tactical handling of submarine-launched cruise missiles depends to a large extent upon the mission of the submarine and its weapons. While Soviet cruise missile submarines are intended primarily for use against US Navy carrier-based task groups, American SLCMs have three basic missions: anti-ship, anti-submarine and land attack.

For many years the Soviet Navy's primary task was to deal with the US Navy's aircraft carrier-centred task groups, whose nuclear-capable attack aircraft had the potential to operate against targets deep inside the USSR. The tactical problem was that the submarine needed to fire its missiles from a relatively safe distance – estimated to be about 200nm – while ensuring that they attacked the crucial carrier rather than some much less important target in its protective screen. The answer was to use shore-based radio intercept stations to locate the task groups and signal the information to the submarine and to a naval air station; two Bear-D aircraft would then be sent to find and observe the task group, transmitting radar pictures to the surfaced submarine, whose SS-N-3 sent back its own post-launch radar picture to the launch vessel, where the radar operator matched the two pictures, identified the carrier and informed the missile, which then homed on the designated target.

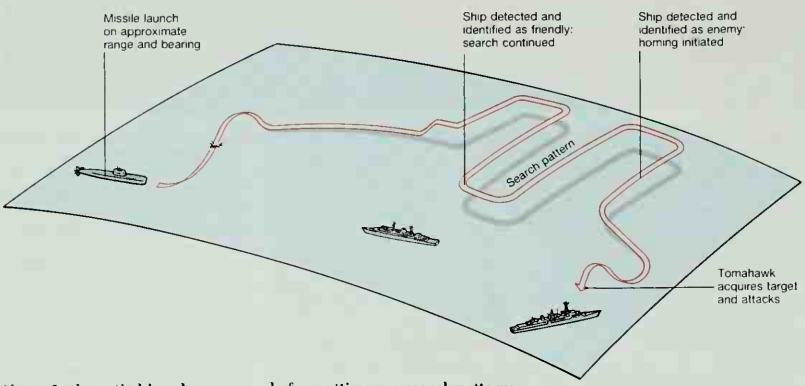
The system had a number of major shortcomings: the survivability of a pair of Bear-Ds in the vicinity of a US carrier task group would appear to be low, and since the SS-N-3A had the general physical and flying characteristics of an aircraft it is quite likely that it would be brought down by the task group's air defence systems. The submarine was also vulnerable for a relatively lengthy period and would be an ideal target for an anti-submarine aircraft.

The Charlie class submarines are able to launch their SS-N-7 or SS-N-15 anti-ship missiles while submerged, which implies that they are capable of reaching a firing solution based on their sonar and that the missile must have sufficiently sophisticated on-board devices to enable it to home on the appropriate high-value targets without any external inputs. The SS-N-19 carried by Oscar class boats has a range of the order of 250nm, is smaller than its predecessors, flies lower, and probably uses satellite data inputs to provide targeting information.

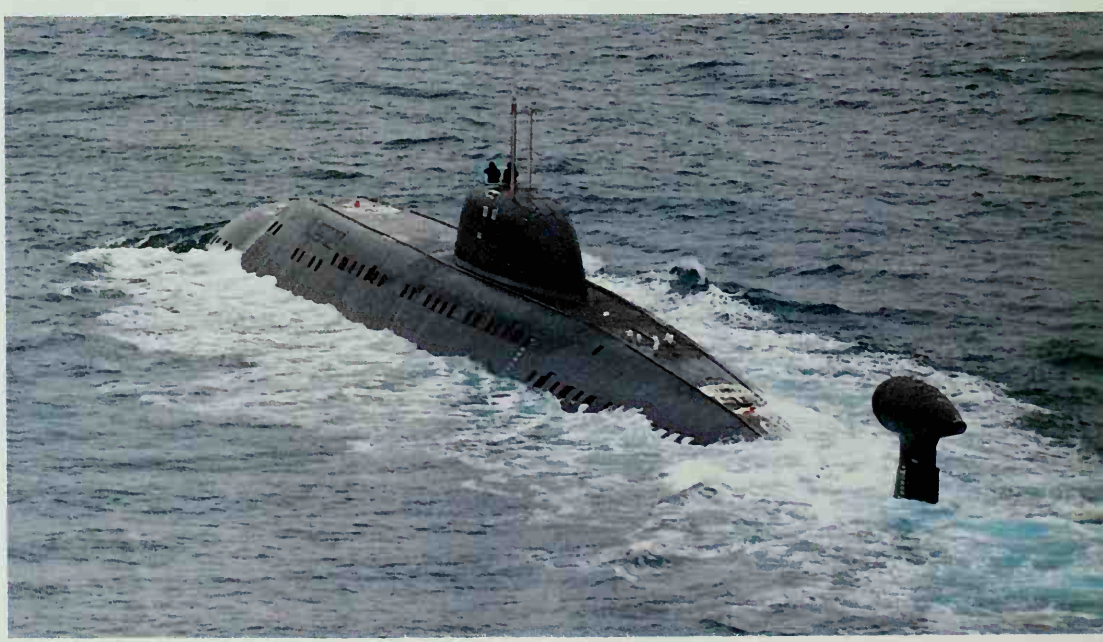
These missile systems give the Soviet Navy a very effective capability against NATO task groups. In a period of tension SSGNs would shadow NATO fleets, and it would be very difficult for NATO forces to detect and shadow all of them all of the time, so they would possess the initiative, being able to launch at will as hostilities started, while their missiles would be very difficult to counter.

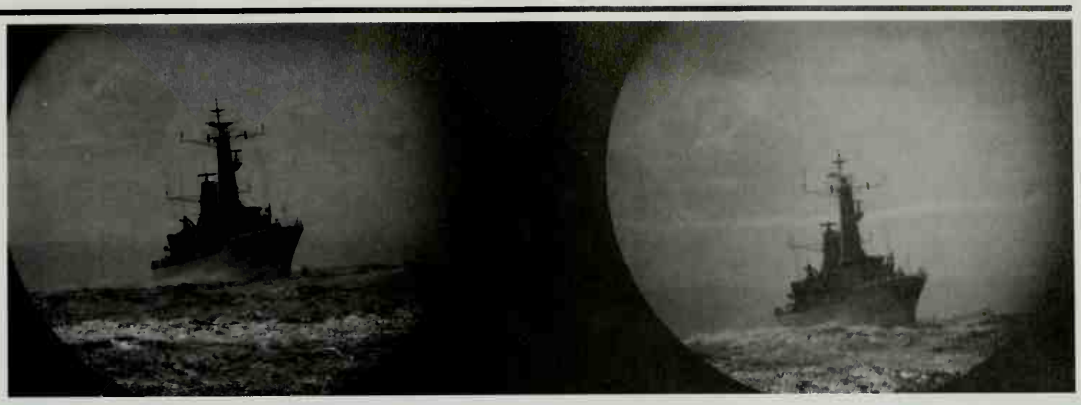
No other navy has an equivalent dedicated cruise missile submarine, although the US Navy now uses the Tomahawk submarine-launched missile in an anti-ship role. The tactics would be similar, with launch taking place before setting up a search pattern; having located and identified the target it commences its attack. Maximum range is approximately 330nm (450km).

Tomahawk over-the-horizon anti-ship attack profile


Missile launch on approximate range and bearing
Ship detected and identified as friendly: search continued
Ship detected and identified as enemy: homing initiated
Search pattern
Tomahawk acquires target and attacks

Above: In the anti-ship role Tomahawk is launched from a submerged submarine on an approximate bearing and flies towards the area of the target

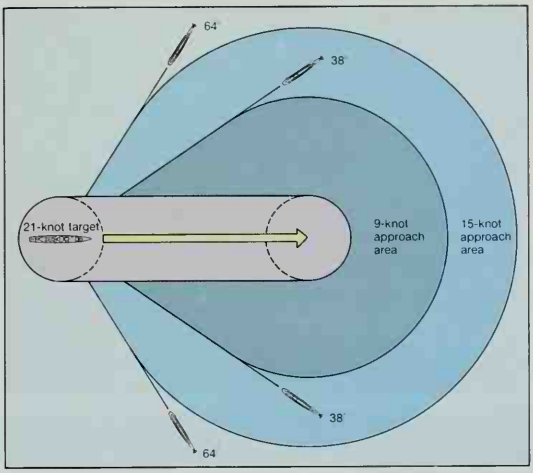




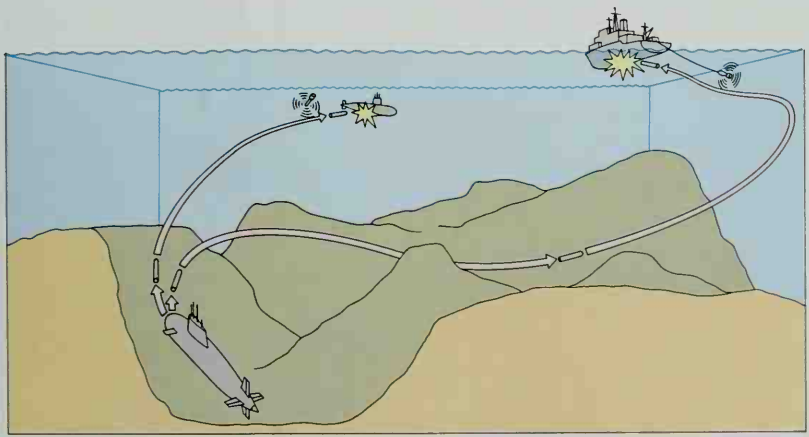
Above: Views through the periscope of a Dutch Walrus class submarine of a van Speijk class frigate on its attack run during a national exercise. In general terms, submarines can detect and attack surface warships at greater ranges than the ships can detect and attack them, unless the ships carry ASW helicopters.

Right: The ability of a submerged submarine to reach the torpedo danger zone (TDZ) of a surface target depends on the speed and bearing of the target and the submarine's own speed. For example, if the target is proceeding at 21 knots, then a 9-knot submarine can reach a launching position on the TDZ only if her initial position is within 38° of the target's bows, while a 15-knot submarine can approach from a larger area and an angle of up to 64°. A diesel submarine's battery endurance reduces rapidly with speed.

Submarine approach areas



Tigerfish tactical employment



Left: A Soviet Victor III SSN shows the unique rudder-mounted pod whose function has not been published in the West. The ability of such vessels to travel at high speed, manoeuvre at high rates and remain submerged for protracted periods means the era of the submarine dogfight is here.

Above: An underwater ambush using the terrain of the sea-bed to hide the presence of a submarine is now a feasible operation. The scenario depicted here utilises the tactical flexibility of the Marconi Tigerfish torpedo to show how surprise attacks could be carried out against surface or submerged targets. This weapon uses wire guidance in the initial stages of the attack up to the point where the torpedo's on-board active/passive 3D sonar homing system can assume autonomous control for the final run to the target; the on-board computer helps it avoid seduction by noise-makers.

from behind the horizon against a high-value Soviet target such as a Kiev class carrier or a Kirov class battlecruiser.

ATTACK SUBMARINE TACTICS

Attack submarines, whether nuclear or diesel-electric powered, can be used for a variety of missions, including operating as escorts to friendly SSBNs; carrying out barrier patrols in the approaches to choke points; keeping clear ocean lanes for task groups or convoys; acting as part of the screen for such task groups or convoys; following up contacts made by other means, such as SOSUS; pursuing independent missions against specific targets such as hostile SSBNs in sanctuaries; and conducting general ocean search.

In a barrier patrol a submarine is likely to operate at very low speed with its sensors in the passive mode. It would normally only use its sensors actively to give a final confirmation of a target's range and bearing, perhaps with a single pulse which would certainly alert the target but without giving away the range and direction of the threat. The problem for the hunter is that if he cannot detect any possible targets he will want to move to another area, which normally involves the possibility of detection. Many submarines, therefore, adopt sprint-and-drift tactics, moving at maximum speed to the new area and then returning to a silent search mode.

A further dilemma for the submarine captain is that while his survival depends on remaining undetected, his role as an attack submarine is to sink hostile submarines or surface vessels and a successful attack immediately confirms his presence.

CLANDESTINE OPERATIONS

Because they can move about the oceans and approach hostile coasts unseen, submarines have long been used for clandestine operations such as the delivery and retrieval of men to and from the shore and ferrying miniature

submarines or submersibles to the vicinity of their targets. The US Navy, in particular, has found submarines ideal for such operations, especially in the wide reaches of the Pacific, and in World War II its submarines were used both to transport raiding parties and to deliver supplies to guerrilla forces. In August 1942 the converted minelayer *Argonaut*, along with the *Nautilus*, delivered a raiding party of no fewer than 211 marines to Makin Island in the Gilbert Archipelago, where they killed all 70 members of the Japanese garrison and destroyed a seaplane base. In another raid on May 11, 1943, *Nautilus* and *Narwhal* delivered a different unit to Attu Atoll with equal success. The British also used submarines effectively on clandestine operations, both around the coasts of Nazi-occupied Europe and in South-East Asia.

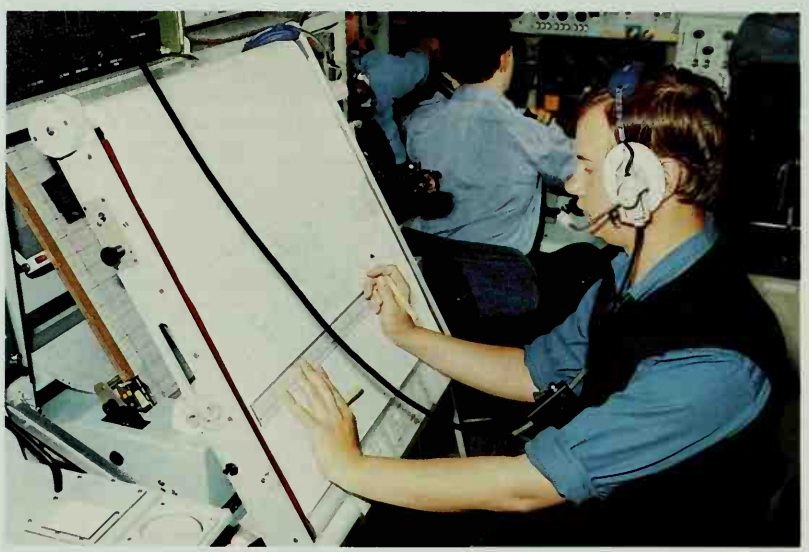
The Italian Navy made excellent use of its submarines to deliver miniature submarines and frogmen to the vicinity of enemy bases. Two boats of the Adua class were converted to carry watertight containers for three assault craft, and two Flutto class boats had four such containers; trials were also carried out with miniature submarines intended for use against ports in Africa and America, and the submarine *Da Vinci* was temporarily converted to carry one on the foredeck. Using such underwater craft the Italian Navy sank or seriously damaged some 63,000 tons of warships and 50,000 tons of merchant shipping.

Since the war many navies have used submarines for covert missions. Virtually any attack or patrol submarine can be used for such purposes, but diesel-electric submarines have proved particularly suitable because of their exceptional underwater quietness. The two largest navies are, however, able to afford specialised submarines for these tasks.

The Soviet Navy frequently uses its large fleet of diesel-electric submarines for covert tasks and considerable resources are devoted to such missions, and in 1981 a Soviet Whiskey class submarine ran aground off the Swedish Kalskrona naval base.

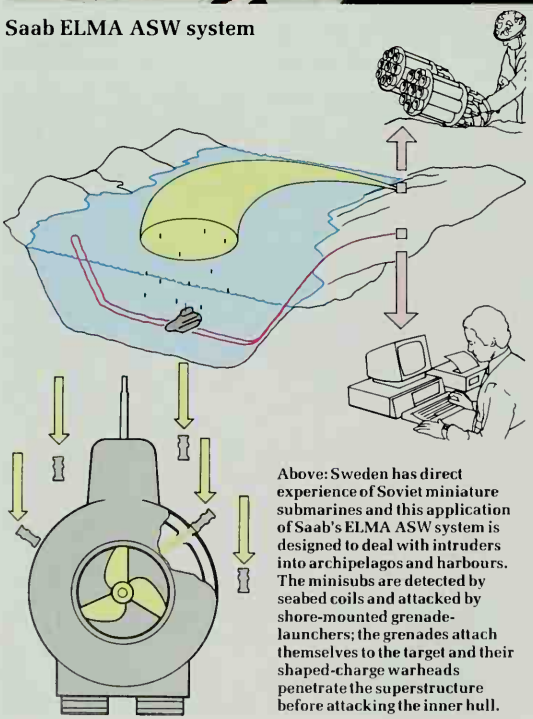
It would appear that any task which has to be performed outside the parent submarine is carried out by men of the naval Spetsnaz units. These Spetsnaz units receive high priority for equipment, the vast majority of which is kept very secret in the usual Soviet way, but one important type of equipment which has recently become public knowledge in the West is the tracked miniature submarines used by naval Spetsnaz units in a blatant reconnaissance of the Swedish naval bases in the Stockholm archipelago in October 1982. These vessels have twin tracks and large single propellers and are taken to the vicinity of their targets by mother-ships, probably the India class submarines which had previously been thought to be intended solely for underwater rescue missions.

Incredibly, it subsequently came to light that a photograph of these

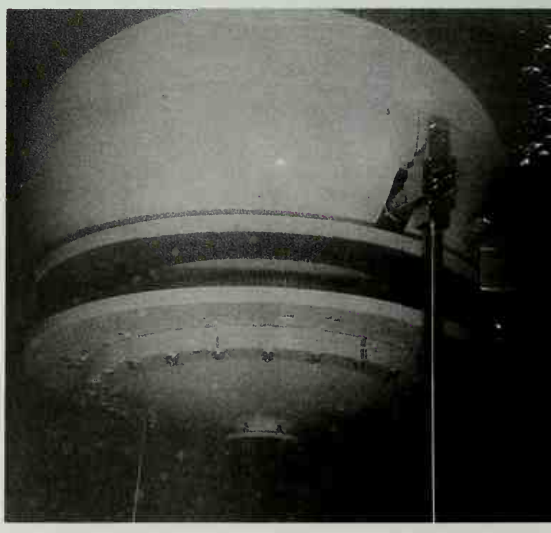


Above: A Royal Navy rating working at a plotting board on board HMS *Trafalgar*. Lacking visual references, submarine crews must maintain and continually update a three-dimensional picture of the tactical environment utilising inputs from all available sensors.

Saab ELMA ASW system



Above: Sweden has direct experience of Soviet miniature submarines and this application of Saab's ELMA ASW system is designed to deal with intruders into archipelagos and harbours. The minisubs are detected by seabed coils and attacked by shore-mounted grenade-launchers; the grenades attach themselves to the target and their shaped-charge warheads penetrate the superstructure before attacking the inner hull.



Below: This Marconi 360° area defence sonar is designed to detect intruders into harbours, landing sites and other sensitive zones. Frequency can be varied for detection of divers or small submersibles, and the sonar can be integrated with night vision devices in a coherent system.

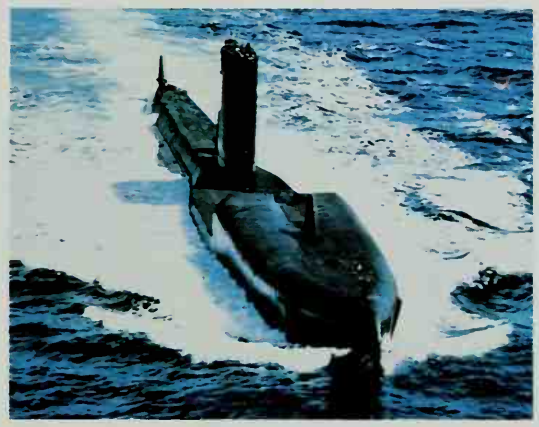
tracked mini-subs was openly published in Pravda in the mid-1970s; they were said by the Soviet authorities to be in use for a search for the lost city of Atlantis, a somewhat fanciful explanation. Unfortunately, nobody in the West seems to have appreciated their possible military significance. Such mini-submarines could be put to a number of uses apart from reconnaissance, such as laying nuclear mines at the exit points from NATO nuclear submarine bases and interfering with NATO seabed installations such as the SOSUS network. One question that inevitably arises is whether other reconnaissance missions have been carried out by these machines – could they, for example, have reconnoitred the British nuclear submarine base at Faslane in Scotland, the French base at Brest, or the many US naval bases?

The British Royal Marines include the Special Boat Squadron, which has over 40 years' experience of operating from submarines, and has in the past few years seen service in Oman and Borneo as well as in the South Atlantic War of 1982. In the last conflict one SBS unit flew from the UK in a C-130 and then parachuted to a submarine in the South Atlantic; this took them to South Georgia, where they were the first British troops ashore. A Royal Navy diesel-electric submarine, HMS *Onyx*, operated in the area throughout the conflict and is probably the boat which undertook most of the clandestine operations. The Army's Special Air Service (SAS) is also believed to have at least one unit capable of operating from submarines, but the Royal Navy has no specialised submarines for these tasks, finding its normal diesel-electric submarines adequate.

US Navy amphibious units include two types of special forces: Underwater Demolition Teams (UDT) and Sea-Air-Land (SEAL) teams. UDTs were raised in World War II: they perform the traditional beach reconnaissance missions as well as destroying specific targets such as roads and bridges in coastal areas and carrying out underwater demolitions. All potential members of SEAL teams come from the ranks of the UDTs and they receive special training to prepare them for their new tasks. This advanced training is needed because they are expected to operate with little support and in restricted waters or on land in a combat environment where they may become involved in encounters with enemy forces.

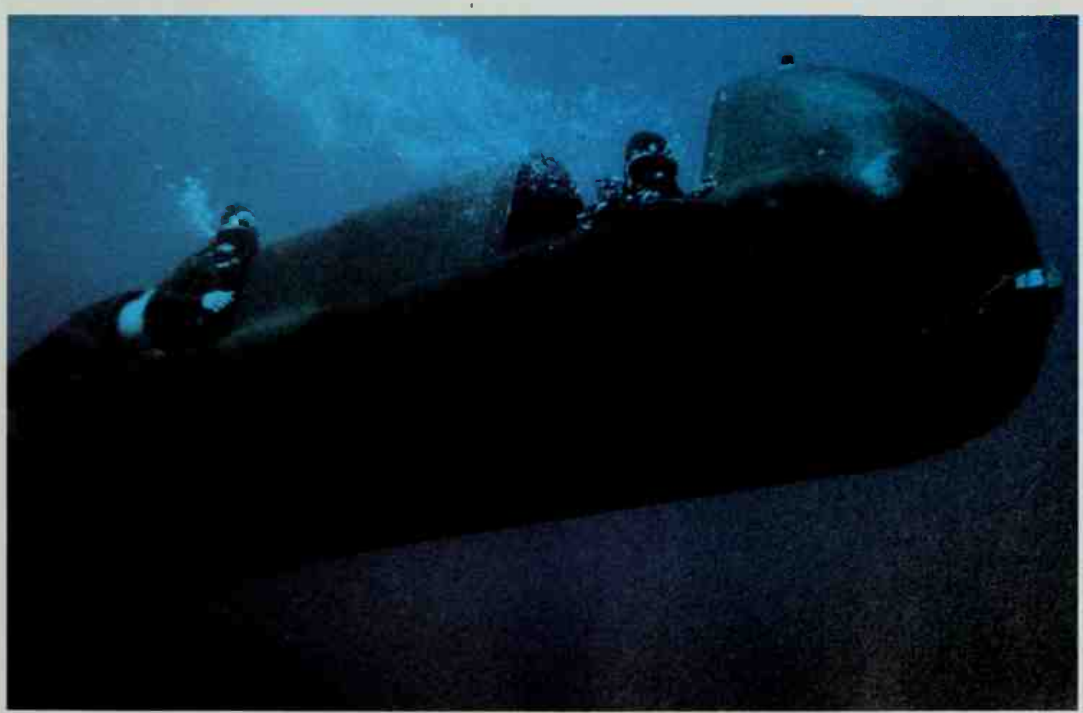
To fulfil their mission SEALs may be carried to the hostile shoreline by submarine and disembark either on the surface or underwater. Each SEAL team comprises 27 officers and 156 enlisted men formed into five platoons, each capable of independent operations. SEAL teams can be expected to carry out similar tasks to the submarine-borne special warfare units of other nations, including reconnaissance, sabotage and demolition. In the conventional phase of a future war they could be used to reconnoitre hostile nuclear installations such as SSBN bases, and to destroy them or inhibit their use in the nuclear phase.

Following its successful use of submarines in raiding operations during World War II the US Navy has always maintained a few transport submarines in service. USS *Grayback*, built as a cruise missile carrier, was converted in 1967 to carry seven officers and 60 troopers and was home-based at Subic Bay in the Philippines, which clearly brought the coastline of most of Asia within her range. The latest move is to convert two former SSBNs of the Ethan Allen class, *Sam Houston* and *John Marshall*, to this role, with cement ballast in the missile tubes and missile-related electronics removed. With virtually unlimited range and operating depths exceeding 984ft (300m), they carry the same passenger load as the *Grayback*, though presumably in greater comfort and for longer distances, and with the potential for a greater amount of specialised equipment to be carried on board.



Above: The amphibious transport submarine USS *Grayback* (LPSS 574). Capable of carrying 67 swimmers, she has been replaced by two former SSBNs, *Sam Houston* and *John Marshall*.

Below: US Navy two-man Swimmer Delivery Vehicle operated by an Underwater Demolotion Team (UDT). UDTs are combined with SEALs in two Special Warfare groups.



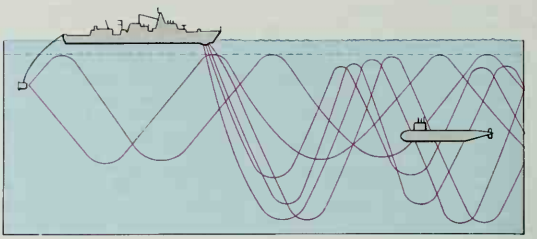
Antisubmarine Tactics

Anti-submarine warfare can be divided into four capability areas according to the platform type and mission – submarine, surface, airborne and surveillance – but each involves similar difficulties, the greatest and most intractable of which is the nature of the ocean itself. If submarines have problems, their enemies, the anti-submarine forces, have an even harder time.

A typical anti-submarine engagement goes through six stages: search, contact, approach, attack, close combat and disengagement. The search may be either general, as part of the protective measures for a convoy or surface group, or directed by information gained from other sensors, such as SOSUS or satellites. The search phase will usually be carried out by the hunting platform – aircraft, surface warship, or submarine – as a patrol following a general search pattern, or as a component of a task group in a designated area. In the latter case, both surface ships and submarines are faced with the problem that the ideal speed of the group may well be greater than the optimum search speed. At this stage, also, the hunter needs to avoid detection, so wherever possible he will use passive sensors coupled with inputs from other platforms.

Contact comprises two elements, detection and classification. Detection is the indication that a possible target is actually in the search area; it will usually be accompanied by a general bearing and followed by classification, the refining process which seeks to confirm that the contact really is a submarine and not a merchant ship, whale or other harmless object, and then to identify it. Examination of the contact's acoustic signature and comparison with the hunter's data bank can lead not only to a broad classification but also to type, class and even, under certain circumstances and with modern equipment, an individual submarine. The approach stage begins with tracking, ideally accomplished by passive means to avoid alerting the target, followed

Variable-depth sonar advantages

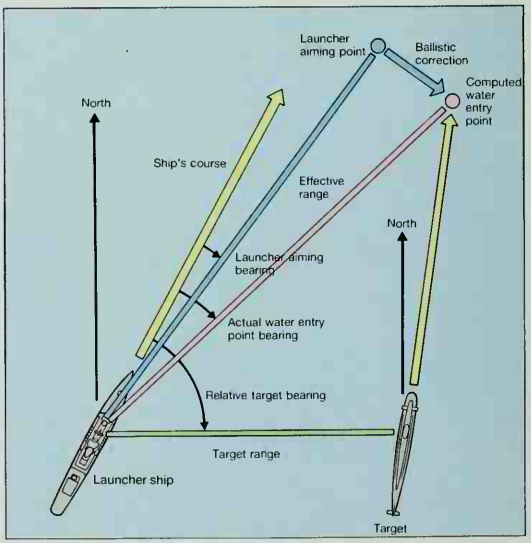


Above: Bow-mounted arrays suffer a number of problems: own-ship noise, pitch due to ship motion and possible shadow zones. Many of these can be overcome by a variable-depth sonar, which operates below the surface layer, where it is separated from own-ship noise and avoids shadow zones.

Below: HMS *Phoebe* with her Westland Lynx ASW helicopter, the winch for her Type 2031 towed sonar array and port triple STWS torpedo tubes clearly shown.

Above: HMCS *Iroquois* (DDH-280) with one of her two CHSS-4 Sea Kings on the flight-deck and, at the stern, the SQS-505 variable-depth sonar. Although surface-to-surface and surface-to-air weapon systems will be replaced under a modernisation programme, the antisubmarine systems will be retained.

Asroc fire control



Above: The US Navy's Underwater Battery Fire Control System (UBFCS) Mk 114 for Asroc computes the relative speeds and positions of the launch ship and underwater target then aims the missile on a course which will bring it to the optimum water entry point, having compensated for ship pitch and roll and wind.

by localization, when the hunter manoeuvres into an attacking position.

In the culmination of the hunt, the attack stage, the hunter must be able to launch its weapons with a fair degree of confidence that the target will be hit, and the primary cause of uncertainty for most navies is weapon, especially torpedo, performance. Consequently, normal submarine practice is to fire torpedoes at about half their theoretical effective range, nominally about 10 or 12 nautical miles, which in relative terms is very close indeed. Even though most modern torpedoes carry their own acoustic sensors, and many have wire-guidance links back to the launcher, there are still many limitations which affect their chances of a successful engagement.

If the initial attack is a failure a close-combat phase ensues in which the protagonists seek to eliminate one another. In the case of submarine-versus-submarine engagements this resembles two fighter aircraft wheeling and manoeuvring in a dog-fight, identifying and evading hostile weapons while trying all the time to deliver the fatal blow themselves. This is the one phase of anti-submarine warfare in which the mechanical excellence of the submarine is the primary factor.

The final stage – disengagement – takes place in a return to the previous conditions of quiet, undetected operation, and a resumption of the search phase.

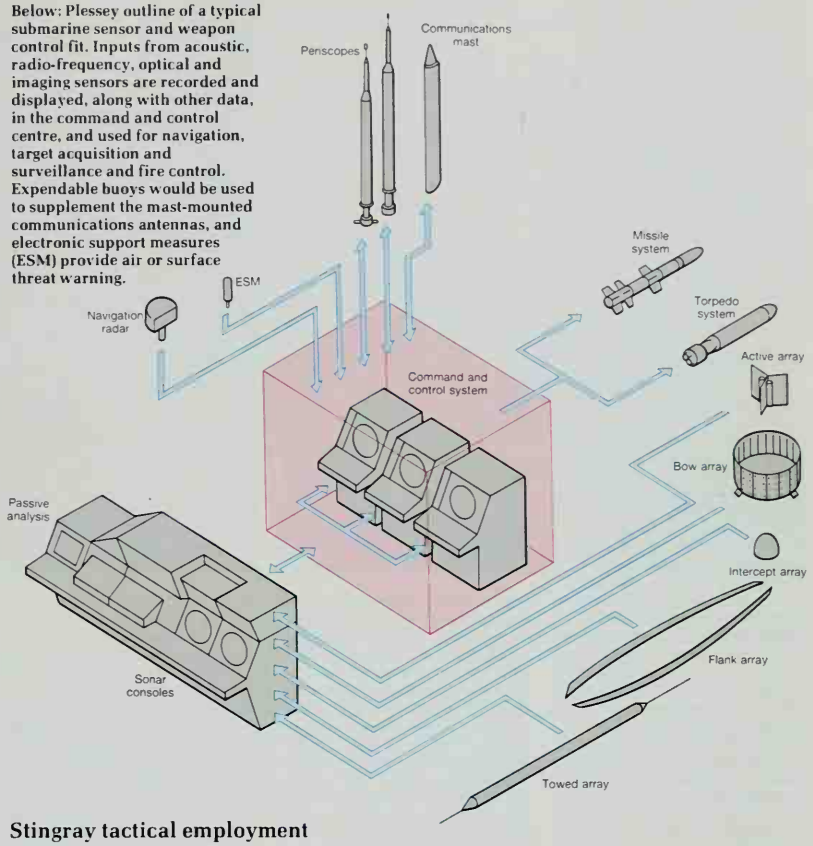
SURFACE ASW

The aim of anti-submarine warfare, to deny the enemy the effective use of his submarines, can be achieved either by destroying the vessels or by adopting tactics and manoeuvres that render their operations ineffective. Of all the types of naval warfare this is the one that most occupies the thinking of contemporary naval strategists and tacticians. New ASW platforms, weapon systems and sensors are continuously being developed and the majority of today's navies devote the major part of their expenditure to this discipline.

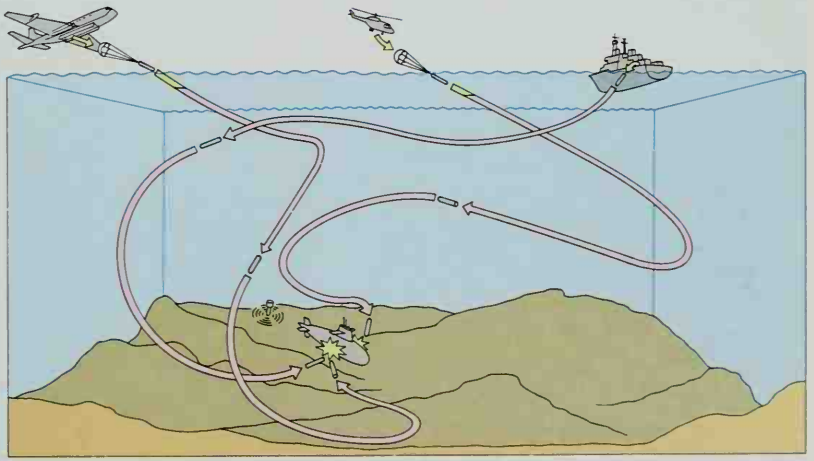
Modern attack submarines have two main roles: first, to search for and destroy enemy surface vessels, both warships and civilian, and secondly to attack other submarines. To achieve these ends effectively, they are fast, able to take maximum advantage of ambient oceanic conditions by operating effectively at various depths, and capable of spending prolonged periods at sea without outside support. Most importantly, they are fitted with detection systems capable of locating targets at considerable distances and carry weapons that are able to destroy their enemies with the minimum risk to themselves. All these qualities contribute to the submarine's greatest asset, its

Submarine sensor and weapon systems

Below: Plessey outline of a typical submarine sensor and weapon control fit. Inputs from acoustic, radio-frequency, optical and imaging sensors are recorded and displayed, along with other data, in the command and control centre, and used for navigation, target acquisition and surveillance and fire control. Expendable buoys would be used to supplement the mast-mounted communications antennas, and electronic support measures (ESM) provide air or surface threat warning.



Stingray tactical employment



Above: The Marconi Stingray lightweight antisubmarine torpedo can be launched from fixed-wing aircraft such as the Nimrod depicted here, ship-based helicopters or surface vessels. Because it is inert until it reaches the water – normally stabilised by a parachute – it can be launched immediately a target is detected, which in the case of MAD detection systems is essential, and its on-board computer can discriminate between its target and expendable decoys.

ability to remain undetected, and make it an increasingly difficult target for surface ships.

The parallel development of nuclear power and the streamlined Albacore-type hull have enhanced submarine performance to the point where there are serious doubts about the ability of surface ships to detect SSNs before they attack. In the view of many, the most effective weapon to use against a submarine is another submarine, since it works and fights in the same environment and is therefore able to take advantage of the unique peculiarities of the sub-surface world, and SSNs have come to be used in support of surface forces. Nevertheless, surface task forces must be capable of their own effective ASW operations.

Traditionally, and especially during World War II, captains of anti-submarine ships have set great store by identifying with the thoughts of their opponents. Great stress was placed on knowing how submarines were fought, to the extent that the strengths and weaknesses of individual submarine captains were carefully assessed and their particular tactics were studied in great detail. In a modern ASW action this type of mental battle may still be significant, though it may be more difficult for a modern captain, comfortable and warm in his operations room surrounded by electronic plots, digital radar displays, the glow of dulled red lighting and the constant chatter of voice nets on headsets, to project his thoughts into the thinking of the submarine captain. Nevertheless, it remains important to make the attempt. 'Know your enemy' is a philosophy that serves the military commander well.

Above: One of the most effective of current ASW helicopters, the Royal Navy's Sea King can use radar, dipping sonar or sonobuoys such as the one seen here on its way down, to detect and locate hostile submarines. A squadron of nine of these aircraft operates from each of the RN's ASW carriers and one is usually operational from each of the Fort Grange class RFAs.

There are few commanders at sea today in any navy who have had the experience of actually hunting a submarine in a hostile environment with the ultimate intention of sinking it. There are, of course, exceptions: both the British and Argentinian navies gained some invaluable experience in the South Atlantic War of 1982, and live anti-submarine operations were also conducted during the Indo-Pakistan war of 1969. It should not be forgotten, however, that, virtually alone among military activities, ASW and counter-ASW tactics can be tested on the high seas between the opposing forces in peacetime with a relatively low risk of escalation, albeit without the intention or the likelihood of destruction.

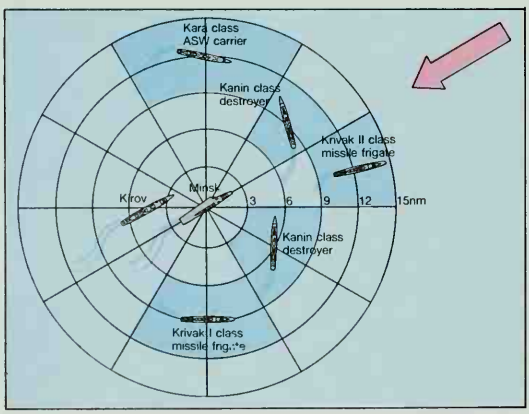
Submarines still use some of the old techniques, especially those that are enhanced by the speed of the modern boats. One example is the sprint-and-drift tactic, in which a nuclear submarine makes a noisy high-speed dash followed by a period of total silence as it drifts towards its target.

Right: A crewman aboard a Royal Navy Sea King prepares to let go a passive sonobuoy. The buoys are laid in patterns, the return signals being analysed to give a precise fix on a target.

DEFENCE OF SURFACE FORCES

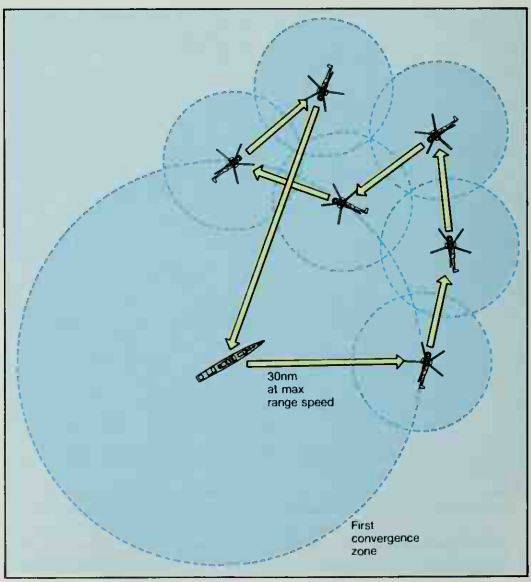
There are two basic situations in surface ASW: the defence of purely military forces and the protection of merchant shipping. The main areas of naval conflict in any future war are likely to be the North Atlantic – particularly the Norwegian Sea – the Baltic and the Mediterranean as far as NATO and the Warsaw Pact are concerned, and the northern and central Pacific in a conflict involving the

Task force protective screen

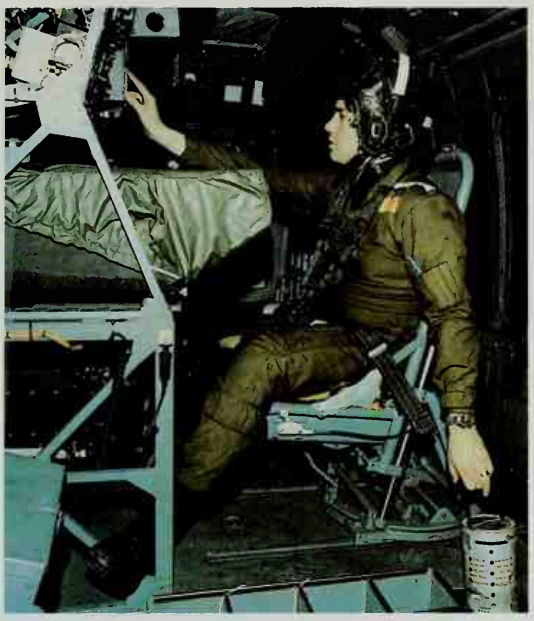


Above: Typical disposition of a Soviet task force, with the main body (*Minsk* and *Kirov*) changing course every few minutes to reduce the submarine threat, while the outlying escorts are allocated patrol sectors of some 60-72sq miles (155-185km^2) each.

ASH-3H ASW mission profile



Right: With a total time on station of 3hr 40min an Italian Navy Sea King can spend half its time hovering to deploy its AQS-18 sonar, which has a maximum range scale of 20,000 yards (18,500m), and half transiting at max endurance speed.



USA and its allies and the USSR.

It is important to consider how a large task force would proceed. The concept of the protective screen around the main body is all-important, as it seeks to ensure that the specialisation of each unit, whether surface or airborne, can be exploited to the full. In the inner protection zone are the active-sonar frigates and helicopters and to allow control and to ensure that the area is fully sanitised each vessel and helicopter is given a defensive sector, normally of about 60-72 square miles in area, and each ship manoeuvres constantly to deny attacking submarines the information they need to set up a firing solution for their weapons. Ships use mainly hull-mounted sonars, while many units, particularly the larger ones, tow noise-makers to decoy any possible acoustic torpedo attack.

Outside this inner zone, the next area is patrolled by ships and aircraft using passive sonar devices. Surface ships use towed arrays such as the American TACTAS system, while helicopters are more likely to use sonobuoys because of their passive capabilities and their ability to cover wider sectors than dipping sonars. Next comes the outer zone where, well in advance of the main body, long-range maritime patrol (LRMP) aircraft utilise the full range of detection devices, including radar, both directional and non-directional sonobuoys, MAD and the Mark 1 eyeball to feed constant information into the aircraft's computer system. Such aircraft are armed with torpedoes, missiles and depth charges for

Above: Inside an RN Sea King, with the control panel for the Type 195 dipping sonar on the right and the sonobuoy operator's position on the left. An advanced processing and display system helps streamline operations.

Below: A Soviet Navy Mi-14 Haze ASW helicopter approaches a Kashin class destroyer. The Mi-14 is not normally seen operating from ships, but deploys from land bases. It has a chin-mounted search radar and a MAD bird, and almost certainly uses sonobuoys.

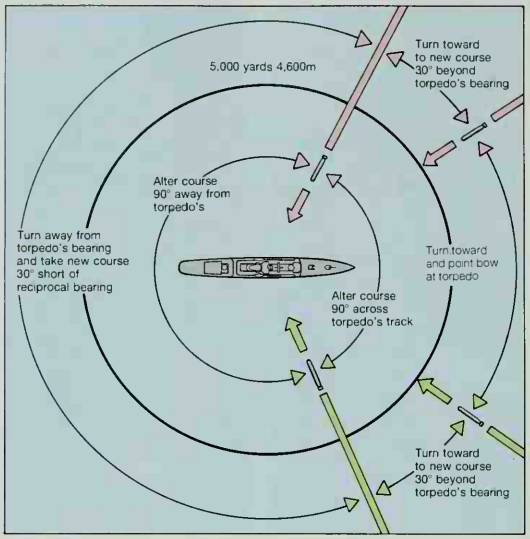
prosecuting an attack if a submarine is detected.

Further out still are the hunter-killer nuclear-powered submarines, well away from their own surface units and the noise of their cavitating propellers, where they are free to manoeuvre. Commanders of such submarines must be able to assume that anything detected moving is an enemy. With the main body carrying out a zigzag course astern of them, restricting its overall speed of advance to probably no more than about 10 knots, the SSN is able to make the most of its speed advantage to cover large areas of sea, although the higher its speed the greater is its noise and consequently the possibility of its detection by an enemy.

With such a screen around him, the task force commander proceeds towards his objective. He must be constantly aware of all the information available to him, both from his own forces and from external sources such as satellite surveillance and intelligence reports, and possible submarine contacts near the main body will demand instant reaction. Attacks can be carried out by a variety of weapons, depending on the target's distance from the fleet: submarines at more than five miles would be dealt with either by helicopters using homing torpedoes or by ships released from their sectors to form a coordinated and independent attack unit. Such attacks would probably proceed according to general pre-planned tactics, with each ship operating within a designated sector based around the submarine's suspected datum. Frigates and destroyers in this situation would launch their helicopters armed with torpedoes.

It must be remembered that positive sonar contact with submarines is notoriously difficult to establish. Ships can search in vain for a long time, either because the contact was spurious in the first place or because the enemy submarine has managed to slip

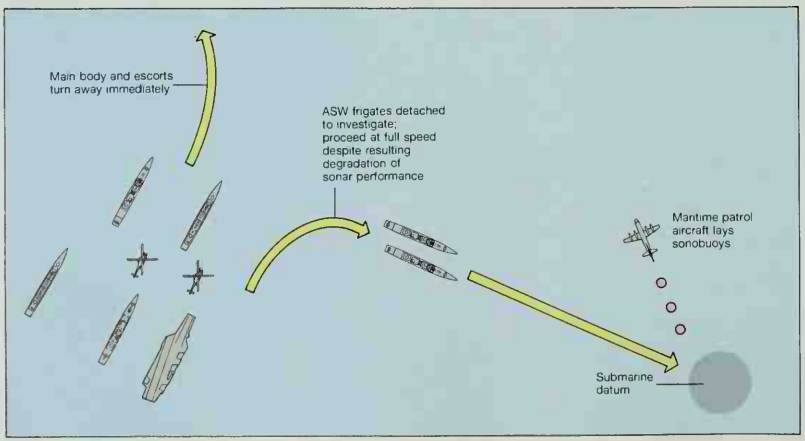
Countermeasures to torpedo attack


5,000 yards 4,600m
Turn toward to new course 30° beyond torpedo's bearing
Alter course 90° away from torpedo's
Turn away from torpedo's bearing and take new course 30° short of reciprocal bearing
Turn toward and point bow at torpedo
Alter course 90° across torpedo's track
Turn toward to new course 30° beyond torpedo's bearing

Left: A submarine's aim is to present a surface ship with a situation where it cannot evade an incoming torpedo. Surface ships must take immediate evasive action on detecting a torpedo to have any change of success, and manoeuvres must be carried out at full speed, as the time available is short – indeed, a 45-knot torpedo detected at 5,000 yards (4,600m) is just 200 seconds from impact, so any evasive manoeuvre must be a virtual reflex action. The ship's aim is to present incoming weapons with the narrowest profile, while also displacing the ship's position as rapidly as possible. If a torpedo is detected at less than 5,000 yards the manoeuvres are slightly different, as there is even less time. The exception to these tactics is if the ship is towing a noise-maker, when an injudicious turn could place the ship between the decoy and the torpedo. Technology is making evasion by surface ships more difficult: many modern torpedoes have wire-guided, acoustic and non-acoustic modes, as well as on-board computers.

Above: Royal Navy frigate HMS *Andromeda* demonstrating her manoeuvrability. Warships need good sensors to detect torpedoes as far out as possible, but quick reactions, high speed and turning ability are also essential to successful evasive actions, and the modified broad-beam Leander is considered to be one of the best.

Task force reaction to submarine contact


Main body and escorts turn away immediately
ASW frigates detached to investigate; proceed at full speed despite resulting degradation of sonar performance
Maritime patrol aircraft lays sonobuoys
Submarine datum

Left: If a submarine is detected approaching a task force and assessed as representing a possible threat, the task force will investigate and seek to destroy it. The most likely immediate reaction of the surface group commander would be to turn the main body away from the direction of the threat while at the same time detaching suitable ASW units – ships or aircraft – to proceed at full speed towards the enemy submarine's estimated position.

away undetected; its commander is, after all, more interested in attacking the main body than the patrolling frigates.

As soon as a submarine contact is made by any unit in the task force, the main body will turn away from the estimated position of the enemy vessel, and at all times zig-zag plans will be maintained. Normally such plans are predetermined, though they can also be varied by the local commander to take account of existing tactical conditions; based on the desired course to be made good, they will allow the ships of the group to alter course together without any further signal communication, and plans can be drawn up to take account of the estimated capabilities of particular types of enemy submarine. Vessels out in the screen, however, are unlikely to follow pre-set zig-zag patterns, though they would need to know the manoeuvres of the main body in order to maintain their correct station.

DANGER ZONES

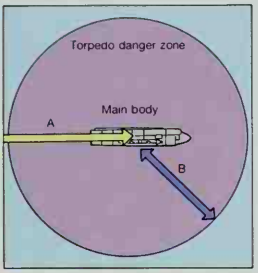
Obviously, the force commander cannot afford to take evasive action every time a submarine contact is reported. Instead, he will normally have to establish areas of danger relevant to the main body, based on his estimate of the capabilities and tactics of the enemy's submarines. For example, even a nuclear submarine commander will prefer to be ahead of his target when he prepares for an attack, and he will have to close to within range of its weapons, two considerations which set certain limits on its area of manoeuvre, and the surface commander can estimate this area, normally referred to as limited lines of submerged approach. Such estimates clearly contain an element of risk, but so do most tactical decisions, and unless he is to manoeuvre his ships all over the sea the naval commander has little option but to make informed guesses. Within these lines can be estimated the torpedo danger zone, and certain defensive actions can then be planned for implementation if a submarine is detected in any given area.

The development of the high-speed, deep-running, well protected submarine has led to demands for ASW weapons with much greater destructive power than the lightweight torpedo, which is simply too small to carry a useful warhead. The nuclear powers have therefore developed nuclear depth bombs capable of being carried by long-range maritime patrol aircraft, ship-borne helicopters and surface ships, which need only be dropped in the vicinity of the submarine to produce a kill. By their very nature, such small nuclear devices exploded underwater produce little or no nuclear fallout, but their use is likely to be restricted by political considerations as well as by the more obvious concern of a commander for the safety of his own submarines.

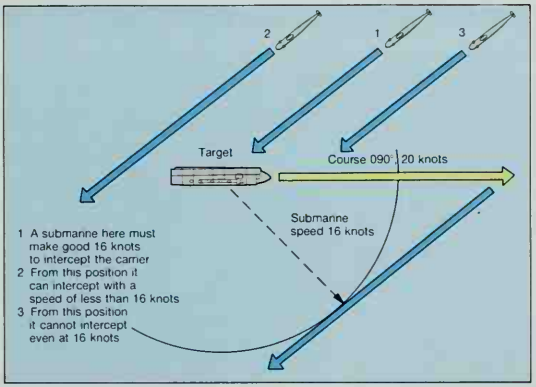
Norway is of crucial strategic importance to both NATO and the Warsaw Pact. It is important in NATO strategy because it stretches northward toward the Soviet Union's main Atlantic naval bases, and it is of prime importance to the Russians since it could provide forward bases from which ships and aircraft could easily harass trans-Atlantic support for the Western Alliance. In a World War III scenario control of the Norwegian Sea, which measures approximately 1,000nm by 800nm, would probably be one of the major areas for naval engagements, and naval forces would have to secure the lines of communication across this sea in support of land and air forces fighting the battle ashore.

Tactically, this could be achieved in two ways: by saturating the area with aircraft and ships and accepting the consequences of a set-piece battle; or by attempting to disrupt the enemy's plans for concentration by keeping forces widely dispersed with greater latitude for manoeuvre, a course more likely to

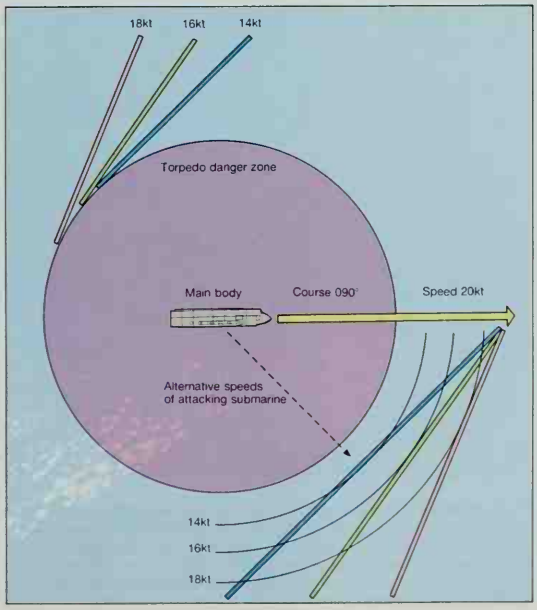
Limiting lines of submerged approach



Left: Submarines pose a continuing threat to any body of surface ships and surface group commanders must be prepared to make instant decisions on whether or not detected submarines pose immediate threats to their forces. A set of criteria for assessing potential threats have therefore been established. These are normally represented as the limiting lines of submerged approach; previously produced as overlays on plotting tables, they are computerised on modern warships so that an assessment can be presented instantly on a commander's attack information screen. The first step is to plot an advanced position based on the centre of the main body and allowing for the running time of an attack torpedo (A). Around this advanced point, a circle designated the Torpedo Danger Zone is created; its radius (B) is the range at which it is anticipated that torpedoes would be fired. This circle advances with the main body.

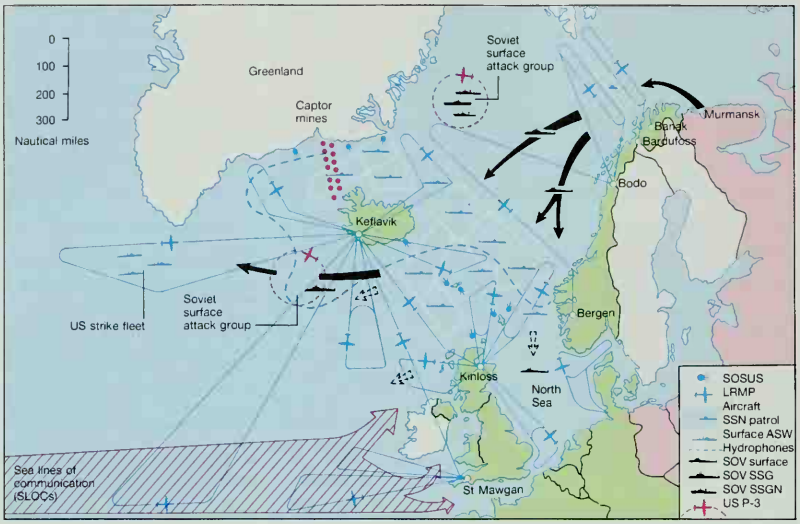

2
1
3
Target
Course 090°
20 knots
Submarine
speed 16 knots
1 A submarine here must make good 16 knots to intercept the carrier
2 From this position it can intercept with a speed of less than 16 knots
3 From this position it cannot intercept even at 16 knots

Left: To assess whether a detected submarine can actually intercept the main body some assumptions have to be made. Although the maximum speeds of different types of submarines vary, during an attack a submarine will always proceeds as slowly as possible to minimise noise and so reduce the risk of detection. Once the speed has been estimated, an arc with this speed as its radius can be drawn (16 knots in this example), and at the same time the main body's course and speed can be plotted (090°, 20 knots). A line drawn from the 20nm mark as a tangent to the arc of the submarine's speed gives the relative course the submarine must make good at 16 knots.



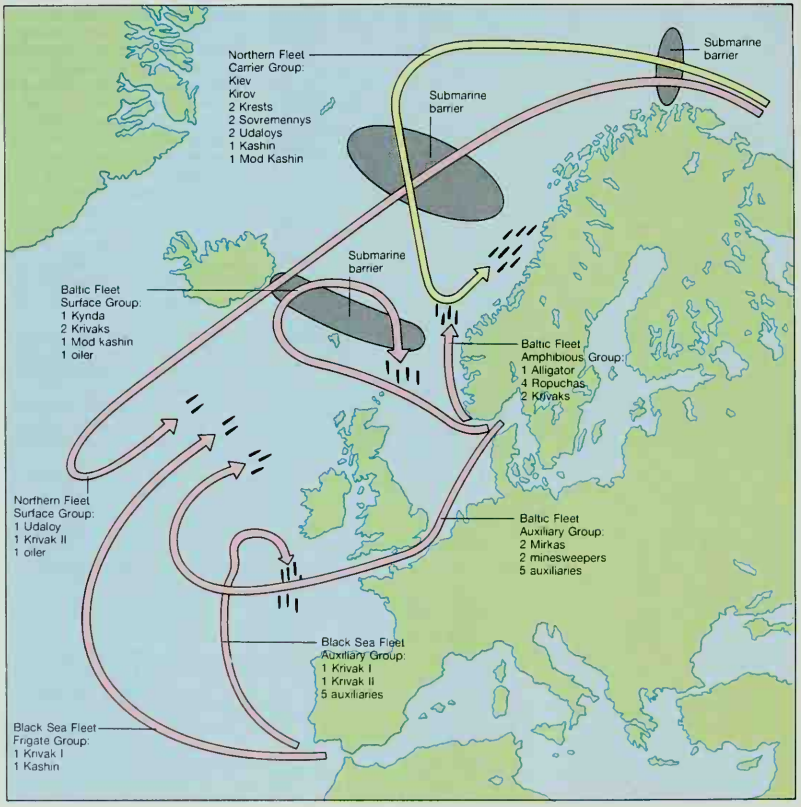
Left: In fact, that the submarine does not actually have to intercept the ship directly in order to reach an attacking position – it needs only manouevre to within torpedo range. In practice, therefore, the two diagrams above are combined as shown here. In addition, several relative courses can be prepared to cover differing submarine speeds – in this example, 14, 16 and 18 knots – and instead of drawing the submarine's relative course direct to the aircraft carrier at the centre it can now be drawn to the periphery of the torpedo danger zone. It can be seen that any detected submarine with an estimated speed of less than 18 knots and a position to the right of the relative courses drawn represents a threat to the carrier. It is also possible to estimate the limitations on the courses a submarine would have to steer from its detected position to close the carrier, thus enabling the force commander to decide with some accuracy where to place his airborne units for maximum protection. (Note that the submarine tracks shown are relative rather than true courses.)

The GIUK gap: NATO's ASW barrier and the Soviet response



Left: Should an East-West conflict start ships and submarines from the Soviet Northern Fleet could be expected to attempt to break out of northern waters into the Atlantic through the Greenland-Iceland-UK (GIUK) gap and into the North Sea, while submarines and surface vessels would also attempt to reach the North Sea through the Skagerrak. These sea passages are designated choke points by NATO, and a great deal of effort has been put into attempting to seal them. They would be covered by a series of layers involving antisubmarine aircraft, fixed monitoring devices such as SOSUS and patrolling submarines. Further, during a period of rising tension US and European strike fleets could be expected to enter the area. This map, taken from Soviet sources, shows a possible NATO deployment. It should be noted that NATO long-range maritime patrol aircraft would be expected not only to cover the choke points but also to support strike fleets shadow Soviet surface groups.

Soviet Summerex 85 naval exercise



Above: Since 1980 the USSR has carried out naval exercises in the Norwegian Sea, the GIUK gap and the waters to the west of the British Isles. These are designed to rehearse Soviet operations into the North Atlantic and also to practise their response to the deployment of a UK/Netherlands amphibious force, which would be NATO's response to a crisis on the northern flank. In Summerex 85 the Soviets set up submarine barriers in the same areas as those they claim would be used by NATO, especially southeast of Iceland, which could lead to a major underwater battle.

avoid a battle and to result in a series of engagements. The size of the Norwegian Sea would demand two or three carrier battle groups, probably in support of amphibious forces. The demands on the control of such a dispersed attacking force would be considerable, but there would be distinct advantages in terms of anti-submarine warfare. Detection of enemy submarines is paramount, and a fast-moving and constantly manoeuvring task force would more easily confuse and deceive the enemy and might well impose on him unwanted manoeuvre and therefore possible exposure.

DEFENCE OF MERCHANT SHIPS

The protection of merchant shipping against submarine warfare is also of vital importance, especially to the Western Alliance. More than 99% of the world's trade is still carried by ships, and every day about 120 ocean-going ships arrive in Western Europe where they discharge three million tons of cargo; in addition, approximately 30 million tons of crude oil are delivered every month to Europe and America. It is estimated that in a major conflict in Western Europe 1,000 ship loads per month would have to arrive to meet the minimum civilian and military requirements, and another 500 ship loads of military stores, equipment, ammunition, fuel and men would have to cross the Atlantic.

The traditional method of protecting merchant shipping in a war environment is to form the vessels into convoys: this permits better control and coordination and allows the defending forces to make efficient use of their limited resources. It should not be thought, however, that convoying is a passive and purely defensive

tactic. On the contrary, it is an aggressive and offensive measure because it forces the submarine to come to the protected convoy and thus fight in the area of the surface force's choosing, rather than vice versa. It also leaves vast empty areas of ocean which the submariners must search fruitlessly.

Many question whether, in an age of nuclear weapons and fast merchant ships, convoying is still viable, but it is perfectly possible to plan for convoys which are spread out over very large areas of sea. Up to 40 ships spaced at five-mile intervals, while still constituting a coherent and controllable group, would cover an area 750 square miles (1,940km^2), and it would require nine or ten 5MT tactical nuclear weapons, all precisely placed, to destroy such a convoy.

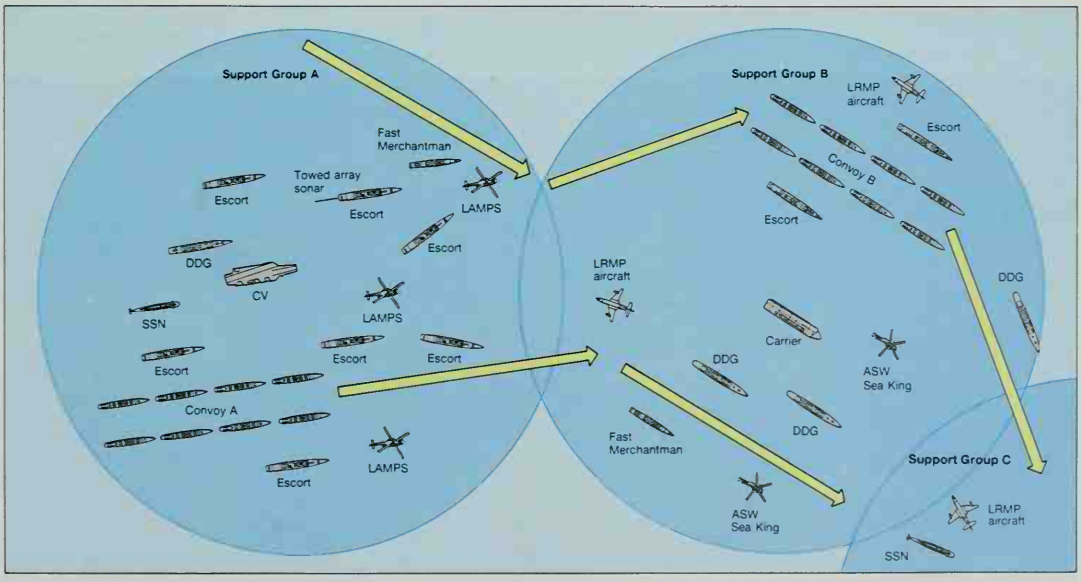
Above: The Standing Naval Force Atlantic (STANAVFORLANT) is made up of ships of several NATO navies which work together routinely to develop ASW drills and ensure close coordination in time of war.

Increasing the space between the ships also makes the attacking submarine's task considerably more difficult, since after an attack on one ship the submarine commander would have to transit several miles before he was in a position to start setting up a new fire control solution. Moreover, having attacked the first vessel he would know that the defending forces would be aware of his location and hunting for him. During World War II it was usual to space ships in a convoy at half-mile intervals; increasing the interval to one mile enlarged the defence area for the escorts by 50 per cent but the risk of loss reduced to about one quarter. Increasing the interval yet again to two miles reduced the risk of loss by a further one-sixteenth, but only increased the convoy perimeter by two and a half times.

Whatever its formation, there are two main ways that a convoy can be protected: by providing it with its own dedicated escorts or by sailing it through areas already occupied and tactically dominated by other supporting groups. The latter is the more likely to be used in a modern war, as it allows more efficient use of limited naval resources and – most importantly – permits passive sonar operations in quiet areas of sea before the fast-moving and noisy merchant vessels arrive. Such support groups would include ships with towed arrays, helicopters and, hopefully, LRMP aircraft, and ideally each group would have at least one SSN in support.

Convoys are normally routed to cause maximum confusion to the enemy, thus minimising the risk of exposure. For example, long-leg

Convoy support groups



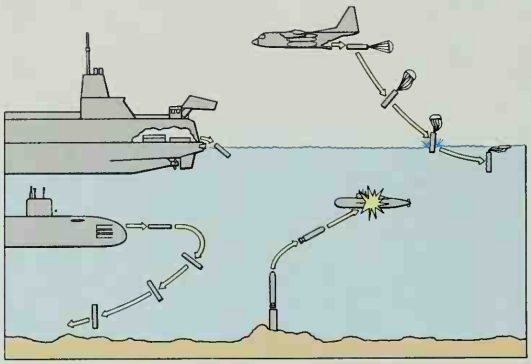
Above: If an enemy uses convoy tactics he forces a hunting submariner to go to him, rather than vice versa. Conversely, the submarine threat compels the enemy to devote considerable resources to protect his convoys. In the case of NATO's supply routes across the Atlantic, the routing of convoys would have to optimise the use of limited naval resources. This diagram shows support groups being used to sanitise areas in advance of transiting convoys. The merchant vessels would have only a minimum number of accompanying escorts; indeed, there might only be ASW helicopters based on one or two of the merchantmen themselves. For their part, the support groups would only be dedicated to a convoy while it passed through.

zig-zags, each 10-12 miles (18-22km) in length, with alterations of course of 30-40°, make it particularly difficult for an attacking submarine to get into the grain of a convoy, while the support groups advance their positions as necessary. In addition, groups should have their own air cover, which should aim to destroy any shadowing aircraft in order to deny the enemy as much information as possible and thereby force him to reveal his whereabouts.

In order to reach a firing solution, a submarine captain has to sort out what is going on on the surface. Shore authorities will pass on any available information, provided by satellite and air reconnaissance and other intelligence sources, but this is inevitably out of date by the time it reaches him. Moreover, the submarine's own on-board sonar information may well be confused, especially as fast-moving convoys make a good deal of noise, which would often be augmented by acoustic deception equipment. To resolve such anomalies the submarine may be forced to approach the surface to use its radar, which will almost certainly be detected by the defenders' ECM equipment and give them a bearing on the submarine's position extremely quickly. And the submarine will certainly use its periscope, which can be detected by the radar of a long-range maritime patrol aircraft.

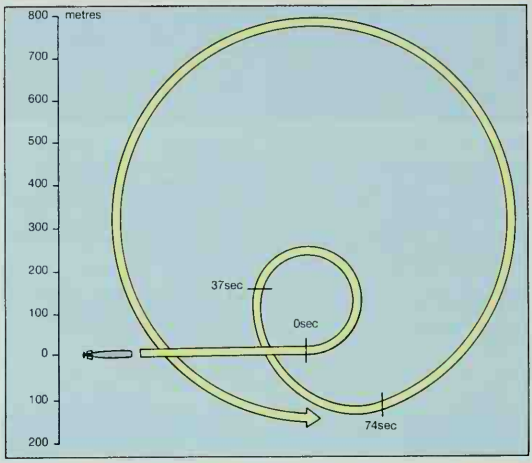
If a submarine has to transit at high speed to close a convoy, the risk of detection is again increased. In the last war submarines enjoyed a speed margin of 16:6 over the convoy, but only when the submarine was running on the

Hammerhead tactical employment



Left: The Marconi/Loral Hammerhead advanced sea mine concept involves an antisubmarine torpedo contained in a 21in (533mm) diameter tube and is designed for offensive and defensive use against both submarine use surface targets. Intended to be able to be positioned beyond the continental shelf and to be laid by aircraft, surface ships or submarines, it is designed to sink to the ocean floor and rest there in a vertical attitude, lying in wait with the torpedo sonar operating in the passive mode. When a target has been detected, tracked and classified the torpedo will be released at the optimum moment to ensure maximum lethality closing on its target with active sonar.

Whitehead A.244/S search pattern



Left: For many years torpedoes simply followed a straight course after launch, which meant that if the initial alignment was wrong or if the target detected the approaching missile and took evasive action, it missed. Modern torpedoes' though still aimed at the target, have an autonomous search capability which enables them to carry out their own search pattern if no target is encountered. The Italian Whitehead A.244/S torpedo, for example, is launched when the ship has manoeuvred into a launch area that gives the required hit probability and travels on a pre-set bearing and at a pre-set depth with its acoustic head activated and searching for the target. After a straight run of predetermined length, if the torpedo has not acoustically acquired the target it initiates a curvilinear search pattern which can be either a constant-depth spiral (shown here) or a helix.

surface. Today that margin is approximately 30:17 with the submarine submerged – and over 40:17 in the case of some Soviet submarines – but whereas 17 knots is a speed easily sustained by a modern warship, a speed of 30 knots submerged makes a submarine very vulnerable to detection.

THE MISSILE THREAT

Torpedo-firing submarines are only one type of threat. Convoys are also liable to attack from missile-firing submarines such as the Soviet Echo class using target acquisition information passed to them either by satellites or reconnaissance aircraft. The range of the Echos' SS-N-3 Shaddock missiles could be as much as 300nm (555km), but the submarine would have to surface before it fired and would therefore make itself vulnerable to detection. The Soviet Charlie class boats can launch SS-N-9 Siren missiles while still submerged, but their range is one-third that of the Shaddock. Either threat should be more easily containable in the support group type of convoy screen, where point defence systems such as Seawolf can provide cover in case of missile attack and electronic counter measures will aid confusion and deception.

The essential principle of tactical defence of a convoy depends on confusion of the enemy, which in turn will force that enemy to show himself, however briefly. Then, as in all naval warfare, once detected the submarine should be destroyed before it can manoeuvre into an attacking position.

Above: A Soviet Victor III caught on the surface by a patrolling Lockheed P-3 aircraft. Well over 600 P-3s have been built for the US and many foreign navies and the type will be in service well into the next century.

AIRBORNE ASW OPERATIONS

The use of aircraft in the ASW battle started in World War I and has continued to grow in importance ever since. Two types of operation are mounted: independent area search tasks under control of a maritime headquarters, and support operations in conjunction with a naval force at sea. The aircraft, whether carrier-borne, land-based or amphibian, fixed-wing or helicopter, is by far the most rapid and effective method of turning a frequently vague long-distance contact into a definite localized target and then conducting the attack. An additional advantage of aircraft is that their presence is very rarely detected by a submerged submarine, which means that in a well conducted airborne ASW operation the first the submarine captain should know about an attack is when he hears the propellers of a high-speed torpedo closing rapidly on his boat.

FIXED-WING AIRCRAFT

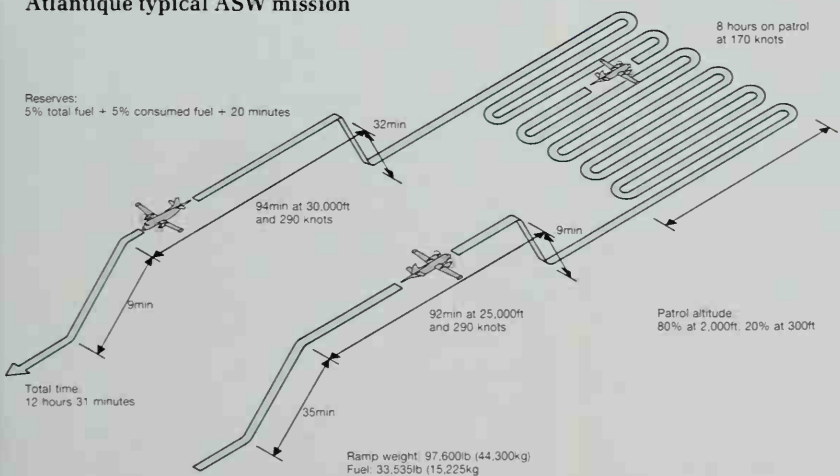
The modern maritime patrol aircraft (MPA) is a unique and highly effective package of sensors, search and target analysis capability, and weapons. All current types are land-based, apart from the US Navy's carrier-based Lockheed S-3A Viking and the few remaining amphibian types, the Soviet Be-12, Japanese PS-1 and Chinese PS-5.

In normal circumstances magnetic anomaly detection is used to give positive confirmation of tracks detected by other means, though in choke points such as the Straits of Gibraltar it can also be used as a primary detection system. MAD can also be used to assist in refining the attack solution, though it is, of course, ineffective against titanium-hulled submarines.

Radar is used to detect surface targets, and even the smallest objects, such as a periscope or the tip of a diesel-electric submarine's snort tube, can now be picked up at great distances. Modern radars are also capable of displaying radar profiles, thus giving virtually instantaneous identification of the target, while periscopes and snorts can also be detected by infra-red devices.

Since sonobuoy performance is so dependent upon the ambient conditions a bathythermograph buoy will frequently be dropped first. This consists of a float which automatically lowers a device which reads temperature and salinity as it goes, the information being transmitted by the surface buoy to the aircraft overhead. Selection of the sonobuoy and its operating mode can then be made:

Atlantique typical ASW mission



Left: One of the most effective antisubmarine weapon systems is the maritime patrol aircraft, of which the British Nimrod is a good example. Long endurance and ample accommodation for sensors are essential.

Above: Typical ASW reconnaissance sortie by a French Atlantique aircraft: an eight-hour patrol more than 600nm from base is possible with standard antisubmarine mission armament of four torpedoes plus more than 100 sonobuoys and a variety of markers and pyrotecnic devices. The speed with which such aircraft reach their patrol area, the size of the area covered, and their ability to switch patrol areas quickly are significant.

sonobuoys can be either directional or omnidirectional and either active or passive. In all cases hydrophone operating depth, surface-to-air transmission frequencies, buoy life and operating mode are set in the aircraft prior to release, though in some modern sonobuoys operating depth can actually be altered after the sonobuoy has entered the water in order to follow a target into a different temperature layer.

The many complex inputs from all these sensors are correlated and controlled by a computerised central tactical system. Such a system is also used to propose weapons solutions and to conduct weapons release.

Maritime patrol aircraft operate either independently on area search tasks, or in support of a maritime force at sea. In the latter case they are normally under the tactical control of the force commander and will usually be deployed as part of the defensive screen at some distance from the surface force itself. They can operate alone on a designated patrol line or, more usually, in conjunction with ASW helicopters from the force's own ships.

In area search tasks the MPA operates independently, usually under the control of a shore-based maritime headquarters. It is normally given a specific area to search, which will frequently be part of an ASW barrier such as that established by NATO in the GIUK gap.

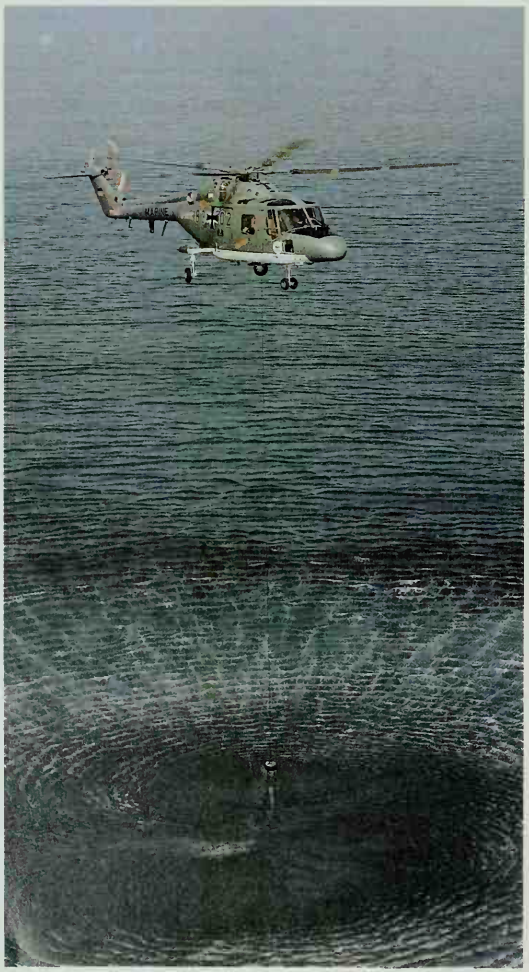
Once a hostile target has been identified the MPA conducts an attack. Most carry various types of torpedo and depth bombs with either conventional or nuclear

Above: An Italian Navy ASH-3D launches a Whitehead A.244/S torpedo. When dropped by a helicopter out of sonar contact the torpedo will be set to start its search pattern immediately.

Right: An SH-2F LAMPS I ASW helicopter deploys its ASW-81 MAD bird. Aircraft usually detect and classify targets with sonobuoys and then make a MAD pass prior to weapon launch.

Below: A Westland Lynx of the Federal Germany Navy with its AQS-18 dunking sonar deployed. The transducer is on a 1,000ft cable and operating modes include moving target indication.

Below right: A Royal Navy Lynx deploys a Stingray lightweight torpedo. The parachute will lower it vertically to the water, where the torpedo will start its search for its submarine target.



warheads. The torpedo has frequently proved to be the weakest link in the entire system and, as described elsewhere, vast sums have been expended on torpedo development programmes in a number of countries.

ASW HELICOPTERS

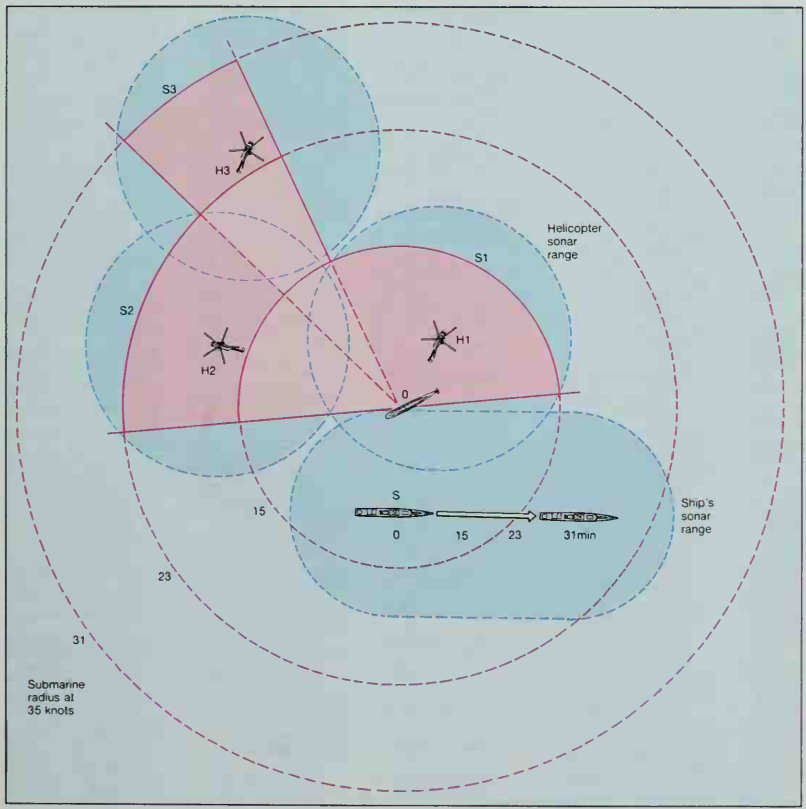
Helicopters have great tactical value in the ASW battle in that they can confer a major and relatively long-range ASW capability on even small surface warships and enable navies who cannot afford expensive, complex and manpower-intensive aircraft carriers to take their own air power to sea. The early ASW helicopters were simple extensions of their ships' sensor and weapon delivery systems, but some modern types are fully autonomous ASW hunter-killers.

A surveillance device unique to the helicopter is the dunking sonar, which is deployed by a winch from a hovering helicopter. When in the hover a helicopter should ideally face into the wind to avoid weather-cocking; it also uses fuel at a much increased rate, and when it is necessary to move to a new search position the dunking sonar must be withdrawn from the water, thus breaking contact. Then, if a submarine track has been firmly established, the sonar must again be withdrawn for the aircraft to start the attack. These problems handicap an ASW helicopter acting alone but they are overcome if two such aircraft can work as a team, since one can always have its sonar in the water, holding the contact, while the other can use its MAD gear under the guidance of the aircraft in contact to establish the submarine's course and then launch an attack, the standard weapons being homing torpedoes or depth bombs.

Dunking sonar has certain advantages over sonobuoys. In some areas, such as the Mediterranean, there are discrete layers of water of differing temperatures, and the interface between them – the thermocline – acts as a barrier to acoustic signals. The dunking sonar, however, can often be lowered through these layers to seek and locate targets which might otherwise have escaped detection.

The passive mode is preferable in certain situations, particularly where it is believed the submarine has no reason to suspect that he has been detected at all and is thus unlikely to take evasive action. The active mode is normally used when time is of the essence – that is, when the submarine is rapidly taking up an attack position against surface targets, or when he knows that he has already been detected. In any case, being hunted by a pair of ASW helicopters using active dunking sonar is a daunting experience for a submarine captain, since he can never be quite sure whether they are still in contact or from which direction the next ping will come.

Dipping sonar: typical ASW operation



Above: Active sonar in ship S moving at 12.5 knots detects an SSN moving at 12 knots; the SSN accelerates to 35 knots. Ship's helicopter at 10 minutes notice deploys at 120 knots to H1, taking two minutes to hover and deploy its sonar to 200m. Contact to operation at H1 takes 15 minutes. Blue circles are areas covered by the helicopter's sonar; solid red lines mark the diminishing areas where the submarine might be: at H1 the helicopter will detect the SSN if it is in S1; if not it moves 9 miles (15km) in 8 minutes to H2 and will detect the SSN if it is in S2; if not, it should be in S3.

Index

Classes of Submarines are indexed by class name and country or origin. Individual boats are indexed by name and pennant number. Page numbers in bold type refer to subjects of illustrations or captions.

A

A class, **15**, 26-7
A.1, A.5, **26**
A.184 torpedo, 74 135, **204**
search pattern, **202**
A.290 torpedo, 135
AGSS 555, **25, 120-1**
AJ-I, 64
AQS-13F, **92**
AQS-18, **92, 196, 204**
ASMs, 123
ASW
technology, 84-95
tactics, 194-205
AUUD/DUUG sonar intercept system, 105, 111
Accidents, 96-8, 188
Accuracy, warheads, 69-70, 186
Acoustics, see Sound; Sonar
Affray, 96
Airborne ASW operations, 203-5
Airborne ELF, **80-1**
Aircraft, 93-5, 203-5
helicopters, 205
mission profile, **196**
Aircraft-carrying submarines, 29
Akula class, **22**, 23, 150
sails, **53**
Albacore, 18, **40-1**
'Albacore' hull form, **40-1**, 124, 132, **152-3, 178, 180-1**
Alexander Brykin, **188**
Alfa class, **22, 44, 106-7**
titanium construction, 56
Alvin reserach submersible, 44
Älvsborg, **133**
Ambush, underwater, **191**
Andromeda, **198**
Anechoic rubber, 174
Anechoic tiles, **53** 55, **103**
Anteo, 99
Antennas, 80-1, **83**
Anti-aircraft turret, **36**
Anti-ship missiles, 123
Anti-ship rocket-launchers, **88**
Anti-submarine warfare technology, 84-95
tactics, 194-205
Appendage drag, 51-2
Arctic, 188
Aréthuse class, 110
Armament, 64-75
sensor and weapon systems, **195**
see also "Armament" section within the detailed descriptions of each class
Asroc, 88, **90**
Astor, 152
Atlantic Ocean
surface temperature, **46**
topography, 44-5
Atlantique 2, 94, **95, 203**
Attack information screen, **199**
Attack submarines
roles, 195-6
tactics, 191
see also names or pennant numbers
Austere, 80
Automation, 58-9
Avalon (DSRV-2), **99**

B

B class, **15**, 27
B.I. **26**
B57 Mod.1, 93
BGM-109 Tomahawk, 64, **71-2, 130-1, 190**
BRT-1, 83
Badger-D (Tu-16), 95
Balao class, 17, 33, **34**
Ballast keels, 56
Ballast tanks, **50-1**, 54
Ballistic missile submarines, see SSBNs
Baltic choke points, **48**
Bangor (Wash.), **187**
Barbel class, **40, 41**
Bases, SSBNs, **186**, 187, **188**, 189
Bathymetric effects, 47
Bear-D (Tu-95), 95
Bear-F (Tu-20), 94
Belgrano, 9, 173
Belos, 99
Bendix AQS-18 sonar, **92**
Benjamin Franklin class, 126
Besson MB411, **30**
Birmingham, **8**
Black Sea choke points, **48**
Blueback, **40**
Boeing E-6A, **80-1**
Bonefish, 25
Bottom-crawlers, 25
Bow domes, **77**, 115, **118-19**
Bow-mounted hydroplanes, **40**, 41 **120-21, 140, 144**
Brayton-cycle engines, 63
Bremen class, **79**
Brest, 189
Britain, see United Kingdom
B.Ae. Nimrod, **94**, 95
Broad-band processing, 77
Bulkhead, 57-8
Buoyancy, **50-1, 54**
Buoys, communications, **81-2**, 83, **94, 119, 155, 169**
sonobuoys, **196**, 203-5
Bushnell, David, 14

C

C class, **15**, 27
C. 35 **26**
CSS-N-3, 71
Cachalot class, **16**
Carbonero, **22**
Carrier-bases aircraft, **93-4**
cep, 69-70
Challenger, 49
Charlie class, 23, **108-9**
Chemical composition of seawater, 45
Chevaline, **65**, 71, **145**
China
fleet, 65, 71
Type ES5E, **24**
Type ES5G, **23**
Xia class, **20-21**, 189
Chiyoda, 99
Choke points, **48, 200**
Circular area probable (cep) 69-70
Clandestine operations, 191-3
Cleopatra, **96**
Closed-cycle systems, **63**
Cochrane, **90**
Communications, 80-3, 87
buoys, 81-2, 83, **119, 155, 169**
from submarines, 82-3
Computer-aided design, **13**
COMTASS, **86**
Conqueror, 9, 173
See also "Construction" section within the detailed descriptions of each class
Continental shelves, **44**
Control consoles, **63**
Control surfaces, 52-3, 128, **133, 134, 180-1**
Conventional submarines, see SSs
Convergence zones, 48, **49**
Convoys, **200-3**
support groups, **201**
Gormorant, **92**
Countermeasures, defence of surface forces, 198-9
Crew comfort, **58-9**
Cruise missile submarines, see SSGs; SSGNs
Cruise missiles, see SLCMs
Cruiser submarines, 30
Cubera, **34**
Currents, **47**
Cuttlefish, **16**

D

D class, 15, **16**, 27, 29
D.2, **26**
DDG-21 (Cochrane), **89**
DSRV-1 Mystic, **98-9**
DSRV-2 Avalon, **99**
Danger zones, **191, 199-200**
torpedo danger zones (TDZ), **191**
Daniel Boone, **127**
Daniel Webster, 126
Daphné class, **73, 110-1**
Dassault-Breguet Atlantique, 94, **95**
Deactivation, 127, 177
Deep scattering layer, 48
Deep sea rescue vehicles, 25, **96-9, 120-1**
Deep sound channel, **48-9**
Defence
of surface forces, **196-9**
or merchant ships, **200-3**
Degaussing, **87**
Delta class, **20, 112-3**
Depth charges, 89
Depths
oceanic, 44-5
operating, **44**
Design, 50-5
computer-aided,**13**
future, 59
SSs, 24-5
SSBNs, 201
US policy, inter-war, 32-3
see also "Design" section within the detailed descriptions of each class
Detection
aerial, 203
capability, US, **187**
Deterrent, ultimate, 186
Diesel-electric propulsion **61-3**
DIFAR sonabuoy, **94**
DIMUS, 41, 127, 131
Disasters, 96-8
Disposition of task forces, **196-8**
Diving, **54**
depths, **44**
and hull design, 51
Dolfijn class, 55, **103**
HMS Dolphin, **25**
USS Dolphin, **25**
Dounereay, **61**
Draken class, **133**
Dreadnought, 24, 173
Dunking sonars, **92-3, 197, 204-5**

E

E class, 15-16, **26-9**
E.1, E.2, **26**
E.14, **27**
E.22, 29
E.31, **28**
E.47, **29**
E-6A, **80-1**
EC-130 Hercules, 81
EDO SQR-18A TACTAS, **86**
EH-101, 94
ELF, 80-1
ELMA ASW system, **192**
EQS-6 sonar, **143**
Early submarines, **14-15**
Echo class, 23, **97, 114-5**, 140
Elbrus, 99
Electric Boat Co, 14, 43
Electrodynamic thrust (EMT), 62-3
Electronic sensors, **79**
see also Antennas
Empennages see Tail empennages
Escape techniques, 98-9
Ethan Allen class, **21**, 126, 193
Eurydice, 97
Evader, 138
Evasive action **198-9**
Excalibur, **39**, 63
Exercise Summerex 85, **200**
Exocet (SM-39), 64, **71**, 105, **148**
Expendible sound velocimeter (XSV), **46**
Explorer, **39**, 63
Extremely low frequency (ELF), 80-1

F

FFV TP 43X0 torpedo, **74**
FFV TP 617 torpedo, **75**
Falklands campaign, 193
Faslane, 187, 189
Federal Republic of Germany
fleet, 12
Bremen class, **79**
TR-1700, **160-1**
Types 201, 205, 164
Type 206, **164-5**
Type 209, **25, 73**, 160, **166-7**
see also Germany
Feniks, 115, **118-9**, 146 177
Fins, 52, 137, 140, 142, 156, 170, 177
fin-mounted planes, 52
Fire control systems, 105, 131, 139, 142 **143**, 147, 155, 171, 173, 181
subsystem, SLBM, 68
First
launch of Trident I, **64**
missile boat, **22**
submarines, **14-15**
British-designed, **15, 26**
nuclear, see Valiant
SSN, see Nautilus
SSBNs, 19, 65
US SSGs, **35**
use as strategic nuclear weapons carriers, **9**
'Fleet Snorkel' modernisation, **35**
Fleets, 12-13
tactics, 186-93
Flore, 98
Florida, **139**
Form drag, 51-2
Foxtrot class, **76, 116-7**, 118, 158-9
France
accidents, 97-8
first submarine, 15
fleet, 12
Agosta class, **104-5**
Daphné class, **73, 104-5, 110-1**
Le Redoutable class, **20**, 126, **128-9**
Narval class, 15, 39
Rubis class, **22**, 24, **44, 148-9**
Surcouf, 17, **30-1**
Front Door/Front Piece missile guidance radar, **123**
Fuel cells, 59, 63
Fulton, Robert, 14
Future submarine design, 59

G

GIUK gap, **200**
Galerna, **104-5**
Gato class, **32-5**
General Belgrano, 9, 173
General Dynamics Corp., Electric Boat Divn, 14, **56**
George Washington class, **60**
German Federal Republic, see Federal Republic of Germany
Germany
WWI, WWII, 16-17
Type IX A, B, **17-19**
Type XVII, 63
Type XXI, **36-9**
Glass-fibre fins, 137, 170
Glenard P Lipscomb class, **22**, 154
Glomar Explorer, 97
Golf class, 19, 20, **118-9**
Gosport, **186**
Graseby 750 sonar, **85**
Gravity, centre of, **50-1**
Grayback, **193**
Gremikha, 188
Griffon, 99
Gudgeon, **38**
Guns
against surface ships, 30-1
US inter-war policy, 33
GUPPY, **34**
Guppy type tank arrangement, **54**
Gymnote, 128

H

H.2, **16**
HAS.3 Lynx, **93**, 94, **204**
HAS.5 Sea King, **92**, 94
HDW
type 209, **25, 73**, 160, **166-7**
type 1500, **8, 96**
HTP propulsion, **37**, 38, **39**, 63
Habitability, **58-9**
Halibut, **9, 22, 60**
Hammerhead tactical employment, **202**
Harpoon, see Sub-Harpoon
Haze (Mi-14), 95, **197**
Helicopters, ASW, 205
ASW mission profile, **196**
Helix, 94
Heracles ORB 31 W radar, **93**
Hercules (EC-130), 81
Herkules sonar, 115, **118-9**
High-test hydrogen peroxide (HTP) propulsion, see HTP
Holland, J P. 14
USS Holland, **14**
HMS Holland, 1, 5, **14**
HMS Holland 3, **15**
Honeywell NT37E torpedo modernisation kit, **72**
Honolulu, **131**
Hotel class, **19, 20**, 118
Hull design, 50-2, 55
'Albacore' hull, **40-1**, 124, 132, **152-3, 178, 180-1**
construction, 55-8
cylindrical form, **131, 138**, 156, **157**, 158
Typhoon class
multiple hull, **158-9**
see also "Design" section within the detailed descriptions of each class
CCS Hunley, 14
Hurmat, **104**
Hydrophone arrays, **76-8, 84-7**
see also Towed arrays
Hydroplanes, 52, **53**55, **59, 134, 157**, 168 177
bow-mounted, **40**, 41, **120-1, 140, 144**

I

Il-38 May **94**
IPD-70 sonar, 135
India class, **120-1**
Infra-red detection, 203
Instability, **50-1**
Islay, **166**
Italy
fleet, 12
Nazario Sauro class, **134-5**

J

James Madison, **64,66** computer suite, **68**
Japan
fleet, 12
Ooshio class, Uzushio class, 178
Yuushio class, 24, **178-9**
Jezebel, **94**
John Marshall, **21, 193**
Juliett class, **122-3**

K

K class, **17**, 30
Ka-322 Helix, 94
Karlskrona, 192
Karlsruhe, **79**
Kashin class, **197**
Kawasaki P-2J, 94
Kilo class, **124-5**
sail, **79**
Kirov, **196**
'Know your enemy', 196
Kockums rescue sphere, **96**
Krupp MaK weapons embarkation and loading system, **73**
Krupp Mak TR1700 torpedo discharge system, **74**
Krupp MaK minelaying system, **75**
Krupp-Atlas CSU3-4, 161
Krupp-Atlas CSU83, 165
Kurier burst transmission, 83

L

LPSS-574, **193**
La Jolla, space and crew comfort, **58**
Lafayette/Franklin class, **20**, 21, **64, 65, 126-7**, 144
computer suite, **68**
LAMPS I, **204**
LAMPS III, 94
Land-based aircraft, 94-5
Largest
SSGN, see Oscar class submarine in the West, see Ohio class submarine ever built, see Typhoon class
Lasers, blue-green, **82**, 86
Last diesel-electric US submarines, 41
Launch subsystem, SLBM, 68
Le Foudroyant, 129
L'Indomptable, **129**
L'Inflexible, **129**
Le Plongeur, 15
Le Redoutable class, **20**, 126, **128-9**
Le Terrible, 129
Le Tonnant, **128**,129
Leanders, **198**
Limiting lines of submerged approach, **199**

Liquid metal-cooled reactors, **42-3**, 60-1, 106-7
S2G, 43
List control, **50**
Lockheed EC-130 Hercules, 81
Lockheed P-3 Orion, 94, 95
Lockheed Mk 500 Evader MARV, 138
Los Angeles class, **22**, 23, **44**, 130-1
hydrophone arrays, **76**
hydroplanes, 52, 53
space and crew comfort, **58**
Los Angeles, **130**
Losses, 96-8
Lynx, **93**, 94, **204**

M

M class, 30
M.1, **16**
M.2, **17**
M-57, 103, **119, 147**
MAD, 86-7, **93-5, 195, 197, 204**
MaK weapons embarkation and loading system, **73**
MaK TR.1700 torpedo discharge system, **74**
MaK mine-laying system, **75**
MARVs, 69-70
MD-100S sonar, 135
Mi-14 Haze, **197**
MIRVs, **69**
MSBS M-4, M-20, **68**, 71
Magneto-hydrodynamic generators (MHD), 62-3
Manoeuvrability, 52
Maritime patrol aircraft, 93-5, 203-5
Martin MS-1, 31
Mast-mounted sensors, see Sensors, mast-mounted
Materials of construction, 56-7
May (II-38), **94**
Mediterranean choke points, **48**
Mendel Rivers, **44**
Merchant ships, defence of, **200-3**
Meteorite, **39**, 63
Michigan, missile tubes amidships, **57**
Midget submarines, 25, 192-3
Mike class, **22**, 23-4
titanium construction, 56
Milestones, 26-43
Minerve, 97
Mines, **73-5**, 88
TSM 3510, **105**
VS M600, 135
Mini-submarines, 25, 192-3
Minsk, **196**
Missiles, **64-74**
launch tubes, 66, 67
the missile threat, 203
see also ASMs; SLBMs; SLCMs; SS-Ns; or missile names, e.g. Exocet
Mochishio, **178**
Murène ASW torpedo, **93**
Mystic (DSRV-1), **89-9**

N

Näcken class, 24, **132-3**
Control console, **63**
Nadashio, **178**, 179
Najad, **132**
Narrow-band processing, 77
Narval class, 15, 39, 110
Narwhal, 154
Nathaniel Greene, **126**
Nautilus, 1801, 14
Nautilus, 1954, **54-3**, 50, **60**, 152
Navigation subsystem, SLBM, 67-8
Nazario Sauro clalss, **134-5**
Netherlands fleet, 12
Dolfijn class, 55
Walrus class, 24, **180-1**
Zeeleeuw class, **180-1**
Zwaardvis class, **180**
Nimrod, **94**, **95**, **195**, 203
Noise
nuclear-powered boats, 61-2
see also Sound propagation
Non-acoustic sensors, 85-7
NATO's northern flank, 199-200
Norwegian Sea, 199-200
November class, 108, 116
NT37E torpedo modernisation kit, **73**
Nuclear depth bomb, 199
Nuclear propulsion 60-1
US development, **60**
see also Pressurised water reactors (PWRs); Liquid metal-cooled reactors
Nuclear weapons, ASW, 90-3
Bikini Atoll test, **91**

O

ORB 31 W, 93
ORB 3211, **93**
Oberon class, **136-7**, 170
sonar, **77**
Oceanic research, 49
Oceans, environment, 18, 44-9
Octopus bow array, 181
Ohio class, **20**, 21, **56**, **138-9**
USS Ohio, **67,87, 139, 187, 189**
control console, **68**
hull form, **56**
missile compartment control and monitoring panel station, **66**
OMERA ORB 31 W, 3211 radars, **93**
Onslought, **77**
Onyx, 193
Ooshio class, 178
Opossum **77, 137**
Orion (P-3), 94, 95
Oscar class, **2-3**, 23-4, **83, 102, 103, 140-1** tiles, **53**
Otus, **136**
Otto fuel propulsion system, **73**
Outlaw Shark system, 72
Over-the-horizon targeting, 23. **190**

P

P-2J, 94
P-3 Orion, 94, 95
PMW 49A torpedo, **89**
Pacific ocean topography, **44-5**
Paints, 52
PARIS, 157, 181
PAT 1, 128
Perch, **34**
Periscopes, **78-9**
Permit class, **22, 23, 142-3**, 154
Pert Spring, 113
Petropavlovsk, 188
Phoenix launch, **57**
Physical characteristics, oceans, 45-7
Pickerel, **51**
Plessey sonars, **85, 92**
Polaris, A-3, 65, 66, 71
Polynarnyi, 188
Poseidon C-3, **65**
Porpoise class, 39
HMS Porpoise, a range target, **57**
Pressure effect, 47
Pressurised water reactors (PWRs), **60-1**
American
S2W, 42
S5W, 126, 142, 152, 154
S6G, 130
S8G, 138
British, PWR1, 144, 156, 162, 172
French, 48MW, 148
Propellers, 62
Propulsion, 60-3
PUFFS fire control system, 131, 139, 142, 155
Pump-jet, **162**

Q

QLA-1 sonar, 35

R

RBU-6000 AS rocket launcher, **88**
Radars
WWII German, **18-19**
detector, 203
FUMB, 39
search
FUMO, 39
SD, SJ, 34
surveillance
Snoop Pair/Rim Hat, **151**
ZPS-6, 179
Rayborn, W F , 66
Reconnaissance, airborne, **196, 203**
Redoutable class, **20**, 126, **128-9**
Reentry vehicles, **69**
see also MARVs, MIRVs
Regulus, **9, 35**, 71
Renown, 145
Repulse, **99**, 145
Research in underwater warfare, 57
Research submarines, 25
Rescue, 98-9
craft, 25, **96-9, 120-1**
Resolution class, **20**, 126, **144-5**
HMS Resolution, 7, **189**
torpedo stowage compartment, **72**
Reverberation 47
Richard B Russell, **154-5**
external installations, **52**
Rickover, Hyman G. 42
Rim Hat, **151**
Rocket-launchers, 88
Roles of modern submarines, 50
Romeo class, 124, **146-7**
Royal Marines, Special Boat Squadron, 193
Royal Navy, see United Kingdom
Rubis class, **22**, 24, **44, 148-9**
Rudders, 124, 177

S

S-1, **31**
S 518 Nazario Sauro, **134-5**
SA322, **93**
SADS, 76
SAS, 193
SEWACO, 181
SH-2F LAMPS I, **204**
SH-60B LAMPS III, 94
SINS (Ship's Inertial Navigation System), 67-8, 139
SLBMs, 64-71
on 1 January 1987 (table), 65
strategic balance (table), 66
strategy, 188-90
A-2, A-3 Polaris, **65**, 66, 71, 126-7, **144-5**
C-3 Poseidon, 65, **126-7**
C-4 Trident I, **64, 66**, 70-1, **126-7, 138**
D-5 Trident II, **66, 69 138-9**
M1-4, 128-9
SLCMs, 71-3
SS-N-21,71, 73, **150**, 151
SS-NX-24, **71**, 73-4, 177
SM39 Exocet 64, **71** 105, **148**
SOSUS, **187**, 193, **200**
SQS-26, 84
SSs, 24-5
105, **31**
171, **16**
193, **33**
240, **84**
302, **35**
313, **34**
337, **22**
524, **51**
563, **38**
567, **38**
580, **41**
581, **40**
SSBNs, 19-21, 186-90
propulsion, **60**
611, **21**
626, 126
627, **64, 66 68**
629, **127**
635, **127**
636, **126**
726, **56, 67,** 68, **87, 139, 187, 189**
727, 57
728, **139**
SSGs, 190-1
282, **35**
SSGNs, 21-3, 190-1
587, **9, 22**
SSNs, **22**, 23-4, 114
propulsion, **60**
class, 21, **59**
571, **42-3**, 50, **60**, 152
575, **42-3**
588, **153**
589, 97, 152
592, 152
593, 47, **60**, 97, **143**
594, **142-3**
597, **60**, 142
609, 611, **193**
639, **52**
671, 154
685, **22**, 154
686, **44**
687, **52, 154-5**
688, **53, 130**
695, **8**
701, **58**
702, **57**
716, **131**
718, **131**
SS-Ns
-3 Shaddock, **22**, 103, **114-5, 122-3**, 190, 191, 203
-4 Sark, 119
-5 Serb, **119**
-6 **176-7**
-7 Siren, 108-9, 203
-8 Sawfly, 20, 122-3
-9, **108-9**, 203
-12 Sandbox, 115
-15, 103, 107, **108-9**, 141, **150, 158-9, 168-9, 174**, 190, 191
-16, 103, 141, **150**, 169
-18 Stingray, 71, **112**
-19, **2-3**, **140**, 190, 191
-20 Sturgeon, 71, **168-9**, 177
-NX-17, **177**
-NX-21, 71, 73, **150**, 151
-NX-23, 71, **113, 188**
-NX-24, **71**, 73-4, 117
SSQ-86 (XN-1), 81
SSQ 954 DIFAR, **94**
Sabalo, **35**
Sails, **53, 79, 131**
Salinity, **46-7**
Salmon/Sargo class, **33**
Salt Lake City, **131**
Salvage craft, **120-1**
Sam Houston, **193**
Sam Rayburn, **127**
San Luis, **167**
Sandbox (SS-N-12), 115
Sanguine, 81
Santa Cruz, **160**
Saphir, **148-9**
Sark (SS-N-4), 119
Satellites
ASW, 86
communications, 83
Savage, 64
Sawfly (SS-N-8), **20, 112-3**
Scamp, **153**
Scorpion, 97, 152
Sea King, **92**, 94, **196-7**
Sea Lance, 88
Seafarer, 80, 81
SEALs, 193
SEASAT, 86
Sea Wolf class, **42-3**, 159
Sea Urchin, **157, 163, 172**
Sensors, 76-9
DSRV, **99**
mast-mounted, 105, 109, 115, 118, 119, 121, 125, 133, 135, 141, 142, **151**, 152, 155, 159, 169, 175
non-acoustic, 85-7
sensor and weapon systems, **195**
see also "Electronics" section within the detailed description of each class
Serb (SS-N-5), **119**
Shaddock (SS-N-3), 22, 103, **114-5, 122-3**, 190, 191, 203
Shin Meiwa PS-1, 94
Ship's Inertial Navigation System (SINS), 67-8, 139
Shock protection, 57
Sidon, 96
Sierra class, **22**, 23, **150-1**
Simrad sonars, **84**
SINBADS, 161, 167
Singer Librascope fire control system, 147
Sippican transceiver, **82**
Siren (SS-N-7), **108-9**
Sirène, 98
Sjöhunden, **132-3**
Sjöormen class, **132-3**
Skate class, **221**, 151
Skin friction, 51
Skipjack class, **22**,23, 41, **152-3**
Smallest nuclear submarine, see Rubis
Snelli's law, 48
Snook 152
Snoop Pair, **151**
Snorkel induction system, **17**
Sonars **76-8, 92-3, 197**, 198-9, **204-5**
active, **76**
passive, **76-8**
DSRV, **99**
AQS-13F, **92**
AQS-18, **92, 196, 204**
BQG-5, 131, 139, 142, 155
BQQ-1, 142
BQQ-2, 142, **143**, 155
BQQ-5, 76, 130-1, 139, **155**
BQQ-6, 139
BQQ-25, 78, 139
BQR-2, 41, 43, 127, 152
BQR-7, 127, 155
BQR-15, **76**
BQR-19, 127, 139
BQR-21, 127
BQR-23A STASS, 78, 131, 155
BQS-4, 152
BQS-6, 142, **143**
BQS-11, 131
BQS-12, 131
BQS-13, 131, 139
BQS-15, 139
CSU 3-4, 161
CSU 83, 165
DBQS-21, 165
DSUV, DUUA, DUUG, 105, 111
DSUX, DUUV, 129
DUUX, 105, 129
EQS-6, 143
Eledone, 181
JP, JT, 35
SQS-36J, 179
Type 186, **77**, 137
Type 197, **77**, 137, 157
Type 2007, **77**, 137, 157, 163, 171
Type 2016, 163
Type 2019, 157, 163, 171
Type 2020, 76, 157, 163
Type 2040, 171
Type 2051 Triton, **77**, 137
ZQQ-4,179
see also Towed arrays; also "Electronics" section within the detailed descriptions of each class
Sonobuoys, **196**, 203, 205
Sopwith Schnieder, 29
Sound-absorbing tiles, **53**, 55
Sound propagation, **46-9** see also Noise
Soviets, see USSR
Spadefish, **53**
Spearfish, 89
Special forces, 192-3
Spetznaz, 192
Splendid, **156**
Sprint and drift, 196
Stability, instability, **50-1**
STANAVFORLANT, **201**
Standoff weapons, 88-9
STASS, 78, 131
Steels, 56-7
HY80, introduction of, 142
NQ1, 170
NS-90, 178
UKE, 172
Stern empennages, **41**, 50, 53, 55, 109, 128, **134, 180-1**
Stingray, **195, 204**
Stingray (SS-N-18), 71, **112**
Stirling-cycle engines, **63**
Stonefish, **157, 163, 171, 172**
Strategic balance, SLMBs (table), 66
Strategic underwater nuclear capabilities, 186-91
Sturgeon class, **22**, 23, **154-5**
external installations, **52-3, 79**
Sturgeon (SS-N-20), 71, **168-9**, 177
Sub-Harpoon, 64, **70, 72-3, 102, 130, 143, 155, 157, 163, 171, 172, 178**, 179
Submarine Active Detection System (SADS), 76
Submarine approach areas, **191**
Submarine fleets, 12-13
Submarine-launched ballistic missiles, see SLBMs; SS-Ns
Submarine-launched cruise missiles, see SLCMs
Submarine tactics, 186-93
anti-submarine tactics, 194-205
SUBROC, 88, **91, 130, 143, 155**
Summerex 85, **200**
Super Puma, **93**
Superb, **157**
Surcouf, 17, **30-1**
Surface
ASW, 84-95, 195-203
DUCT, **49**
effects, 47-8
forces, defence of, **196-9**
stability of submarines, **50-1**
temperature, **46**
Surfacing, **51**
Sweden
fleet, 12
undersea rescue vehicle, **98**
Draken class, **133**
ELMA ASW system, **192**
Näcken class, 24, **132-3**
control console, **63**
Sjöormen class, **132-3**
Västergötland class, **133**
Swiftsure class, 22, **156-7**, 162
Swordfish (USS), **33**

T

TDZ, **191, 199**
TP43XO, TP617, **75**
TR-1700, 160-1
interior layout, **59, 73**
Tu-16 Badger-D, 95
Tu-20 Bear-F, 94
Tu-95 Bear-D, 95
TACAMO, **80-1**
TACTAS, **86**
Tactics
anti-submarine, 194-205
submarine, 186-94
Tail empennages, **4**, 50, 53, 55, 109, 128, **134, 175, 180-1**
TAINS, 72
Tamir 5-L, 147
Tang class, **38**
Tango class, **8, 158-9**
Task force disposition, **196-8**
Tautog, external

installations, **52**
Teardrop hull shape, 50
Temperature distribution, oceanic, **46**
Tench class, 33, 34
TERCOM, 72
Terrain-Aided Inertial Navigation System (TAINS), 72
Terrain Comparison (TERCOM), 72
Thermocline, 46, 48, 205
Thresher, 47, **60**, 97, 143
Thyssen TR-1700, **160-1**
interior, **59, 73**
Tigerfish, **74, 136**, 137
144-5, 157, 163, 166, **177, 172**
tactical employment, **191**
Tiles, **53**, 55
Titanium, 56, 87, 106-7
Tomahawk (BGM-109), 64, **71-2, 130-1**
OTH anti-ship attack profile, **190**
Topography, ocean, **44-5**
Torpedo
danger zones (TDZ), **191, 199**
evasion, **198**
Torpedoes, **73-5, 89, 93**
ASW tactis, 194-205
German, 167
A.184, **74**, 135, **202, 204**
E-14, E-15, **110-1**
F-17, **105, 148**
G7e, **37**
GRX-2, **178**, 179
L3, **110-1**
L5, **105, 148**
M-57, 103, **119**, 147
Mk.8, 137, 173
Mk.14/16, 152
Mk.20, 137, 173
Mk.23, **136**, 137
Mk.24 Tigerfish, **74, 136**, 137, **144-5, 157, 163**, 166, **171, 172, 191**
Mk.37, 152, **160-1, 178**, 179
Mk.45 Astor, 152
Mk.48, **130, 138, 143, 155**, 173, **178**, 179 181
NT37E modernisation kit, **73**
SST-4, **160-1**
Seeal, Seeschlange, **164-5**
SUT, **164-5**
Tp42, TP43, Tp61, **132**
Type 65 wake-homing, **150**, 151, **168-9, 174**
see also "Armament" section within the detailed descriptions of each class
Towed arrays, **76-8, 85-7**, 131, 137, 141, 151, **173, 175**, 181
Trafalgar class, **22**, 24, 156, **162-3**
HMS Trafalgar, internal arrangements, **58-9, 192**
Transient acoustic processing, 77-8
Transmission profile, 48
Trenches, oceanic, **44-5**
Trident
bases, **187**
I (C-4), **64, 66**, 70-1, **126-7, 138**
II(D-5), **66, 69, 138-9**
Trieste bathyscaphe, 44
Triton (USS), **60**
Triton sonar, **77, 137**
Triton (French rescue submarine), 99
Troop-carrying submarines, 25
Truculent, 97
Tullibee, **60**, 142
Tunny, **35**
Turbulent, **51, 162**
Turtle, 14
Type IX A, B, **17-19**
Type XVII, **37**, 63
Type XXI, **36-9**
Type 201, 205, 164
Type 206, **164-5**, 166
Type 209, **25, 73**, 160, **166-7**
Type 1500, **8, 96**
Type 2400, 24
Type ES5E, **24**
Type ES5G, **23**
Types of submarines, 14-25
Typhoon class, **20-1, 168-9**
internal arrangement, **55**

U

U-793, **37**
U-2502, **37**
U-3008, **38**
UGM-84 Sub-Harpoon, 64, **70, 72-3, 102, 130, 143, 155, 157, 163, 171, 172, 178**, 179
UGM-93A Trident I, **64, 66**, 70-1, **126-7, 138**
UH-1, **83**
URV, **98**
UUM-44, see SUBROC
Underwater nuclear explosions, 90-3
Biniki Atoll test, **91**
Underwater sound, **46-7**
United Kingdom
accidents, 96-7
first submarines, **15**
fleet, 12-13
SLBMs, **65**, 71
SSBNs, **20**, 21
SSNs, 24
A-D classes, 15
E class, 15-16, **26-9**
Oberon class, 39, **136-7**, 170
sonar, **77**
Porpoise class, 39, 136
Resolution class, **20**, 126, **144-5**
Swiftsure class, **22, 156-7**, 162
Trafalgar class, **22**, 24, 156, **162-3**
internal arrangements, **58-9, 192**
Type 2400, 24
Upholder class, **170-1**
construction and space allocation, **56**
Valiant class, **22, 145**, 156, **172-3**
Vanguard class, **20**
United States of America
accidents, 97
deep submergence rescue vehicle, **98-9**
Defence Advanced Research Projects Agency (DARPA), 75
development of N-powered submarines, **60**
first submarine, **14**
fleet, 12-13
inter-war design policy, 32-3
SLBMs, 65, 67-71
program, 64-6
SSBNs, **20**, 21
SSNs, 23
Albacore (AGSS), **40-1**, 50
Balao class, 17, 33, **34**
Barbel class, **125**
Benjamin Franklin class, see Lafayette/ Franklin class
Cachalot clatt, **16**
Ethan Allen class, **21**, 126, 193
Gato class, **32-5**
George Washington class, **60**
Glenard P Lipscomb class, **22**, 154
Lafayette/Franklin class, **20**, 21, **64, 65, 126-7**, 144
computer suite, **68**
Los Angeles class, **22**, 23, **44, 66, 130-1**
hydrophone arrays, **76**
hydroplanes, 52, 53
space and crew comfort, **58**
Nautilus, **42-3**, 50, **60**, 152
Ohio class, **20**, 21, **56, 66, 68, 138-9**
Permit class, **22**, 23, **142-3**, 154
Salmon/Sargo class, **33**
Sea Wolf class, **42-3, 59**
Skate class, **22**, 151
Skipjack class, **22**, 23, 41, **152-3**
Sturgeon class, **22**, 23, **154-5**
external installations, **53-3, 79**
Tang class, **38**
Tench class, 33, 34
Undersea rescue vehicles, **96-9**
Underwater Demolition Teams (UDTs), **193**
Upholder class, **170-1**
construction and space allocation, **56**
USSR
accidents and rescue, 97-9
fleet, 12-13
SLMBs, **67**, 71
program 66-8
SSBN strategy, 188
SSBNs, 19-20, 21
SSGNs, 21-3
SSNs, 23-4
Akula class, **22**, 23, 150
sails, **53**
Alfa class, **22, 44, 106-7**
titanium construction, 56
Charlie class, 23, **108-9**
Delta class, **20, 112-3, 188**
Echo class, 23, **97, 114-5**, 140
Foxtrot class, **76, 116-7**, 118, 122
Golf class, 19, **20, 118-9**
Hotel class, **19, 20**, 118
India class, **99, 120-1**
Juliett class, **22, 122-3**
Kilo class, **124-5**
sail, **79**
Mike class, **22**, 23-4
titanium construction, 56
November class, 116
Oscar class, **2-3**, 23-4, **140-1**
tiles, **53**
Romeo class, 124, **146-7**
Sierra class, **22**, 23, **150-1**
Tango class, 8, **158-9**
Typhoon class, **20-1, 168-9**
internal arrangements, **55**
Victor class, **22**, 23, **83**, 108-9, 150, 158, **174-5, 190**
Whiskey class, 23, 38, 124, 146
Yankee class, **19-20, 71, 97**, 113, **176-7**
Zulu class, 116, 118
Uzushio class, 178

V

V-2, 65
VLF, 80, **119, 141**, 169
Valiant class, **22**, 145, 156, **172-3**
Van Drebel, Cornelius, 14
Vanguard class, **20**
Vargen, **133**
Västergötland class, **133**
Very low frequency radio (VLF), 80
Victor class, **22**, 23, **83**, 108-9, 150, 158, **174-5, 190**
Vladivostock, **188**

W

Wake-homing torpedoes (Type 65), **150**, 151, **168-9, 174**
Walrus class, 24, **160-1**
Walther-cycle engines, **37**, 38, **39**, 63
Warhead accuracy, 69-70, 186
Weapons, **64-75**
sensor and weapon systems, **195**
see also "Armament" section within the detailed description of each class
Wedigen, Kapit.-Lt., 17
Welded hull, **16**
West Germany, see Federal Republic of Germany
Westland Lynx, **93**, 94, **204**
Whiskey class, 23, 38, 124, 156
Whitehead A. 184
torpedo, **74**, 135, **204**
search pattern, **202**
Wilhelm Bauer, 39
Wire-guided torpedoes, **74, 75**
see also names of torpedoes, eg Tigerfish
World Wars
I, 16-17, 29
II, 17-18, 26, 33-4
ASW, 196
clandestine operations, 192
communications, 82-3
convoys, 201
World's submarine fleets, 12-13

X

X-shaped empennages, **41**, 53, 55, **133, 134, 180-1**
X-1, 30
X-8 accident, 18
Xia class, **20**, 21, 189
XSTAT transceiver, **82**

Y

Yankee class, **19-20, 71, 97**, 113, **176-7**
Yuushio class, 24, **178-9**

Z

Zeeleeuw class, **180-1**
Zulu class, 116, 118
Zwaardvis class, **180**

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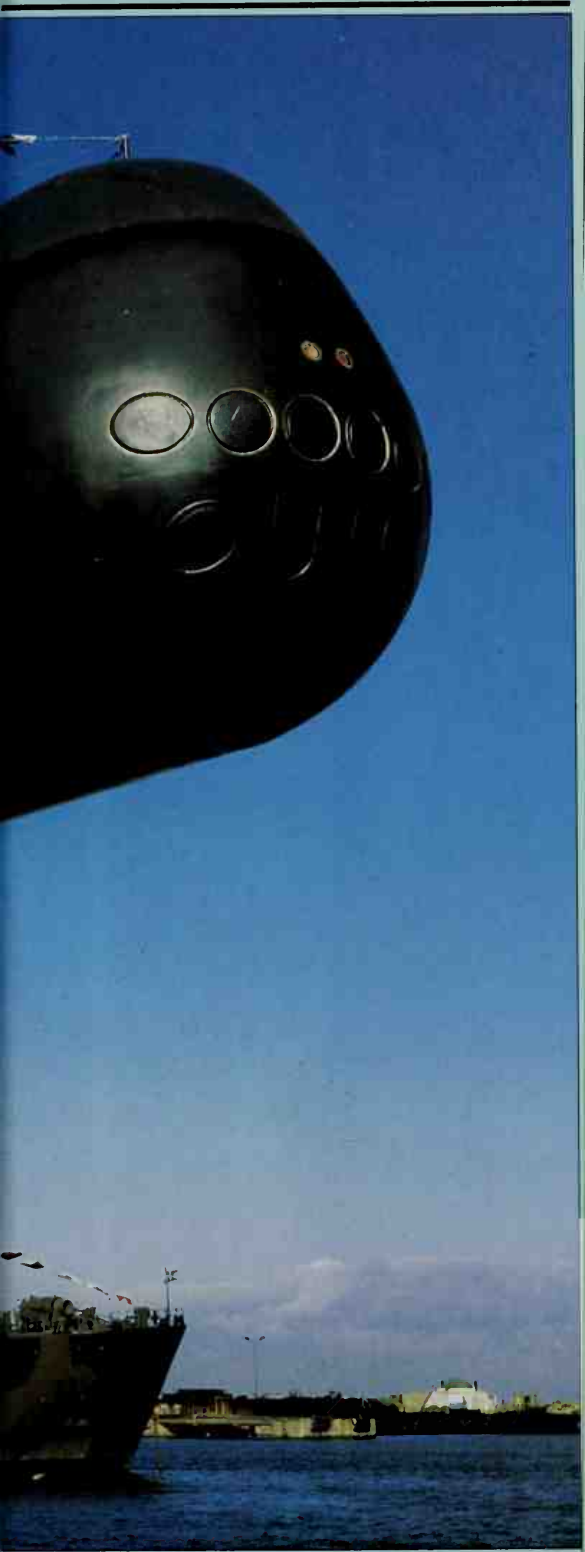

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Jacket printed in Singapore

Military Press

Distributed by Crown Publishers, Inc.
225 Park Avenue South
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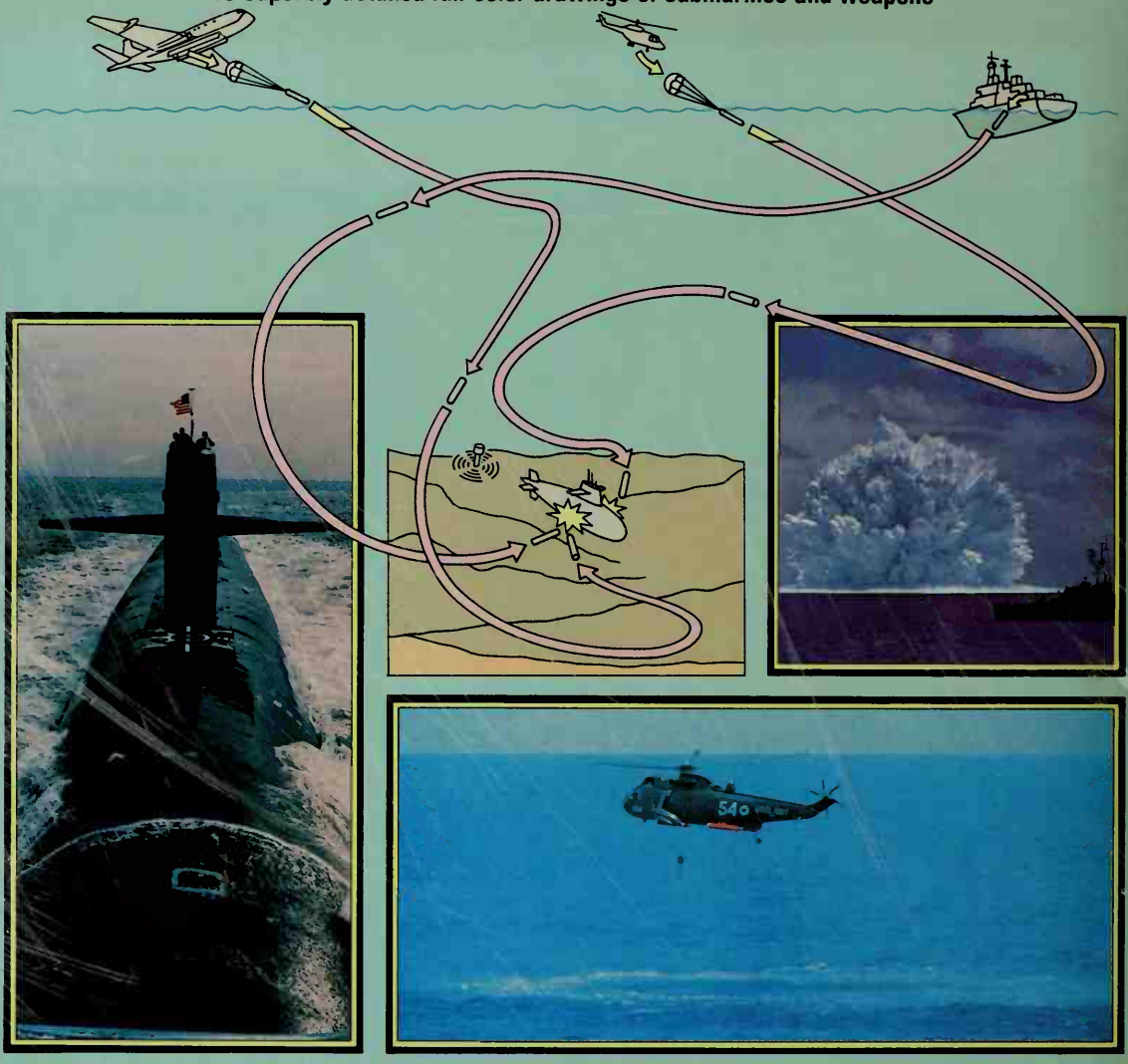

ISBN 0-517-64647-1